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A COMPARISON OF SOME FILTER MATERIALS FOR CORRUGATED PLASTIC DRAINS

by

© MUHAMMAD RIAZ

A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "A Comparison of Some Filter Materials for Corrugated Plastic Drains," submitted by Muhammad Riaz in partial fulfillment of the requirements for the degree of Master of Science.

ABSTRACT

There is a lack of knowledge on the problem of drain sedimentation in Canada. Only in the last few years has there been some research done in Ontario to evaluate materials and methods of protecting underground drains against silting.

In this study, seven filter material treatments and a check were compared in a laboratory model to determine their relative effect on flow of sediments and water to a corrugated plastic drain tube having two types of perforations.

The drain tank model, built of plywood, was 48 inches deep, 18 inches wide, and 12 inches long. A drainage cycle, consisting of ponded water flow and partially saturated flow conditions was simulated in the model. Based on their performance the treatments can be rated as follows:

Rating based on providing protection against sediment movement:

1) Glass fiber mat with glass fiber felt.
2) Tile guard with glass fiber felt.
3) Glass fiber mat with poly-underlay.
4) Tile guard with poly-underlay.
5) Glass fiber mat 270°.
6) Tile guard 270°.

7) Gravel filter.

8) No filter.

Rating based on flow of water:

1 - Gravel filter.

2 - Tile guard with glass fiber felt.

3 - Glass fiber mat with glass fiber felt.

4 - Glass fiber mat 270°.

5 - Tile guard 270°.

6 - Glass fiber mat with poly-underlay.

7 - Tile guard with poly-underlay.

8 - No filter.

For both soil and water discharged, glass fiber mat and tile guard did not differ significantly from each other under similar placement conditions or combinations. There was a significant change in the composition of the sediments discharged into the drain as compared with the original base soil.

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My parents, other family members and friends deserve much credit for the forces which played upon my life to guide me this far.

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Chapter 1

INTRODUCTION

Subsurface drainage is an integral part of a permanent irrigation agriculture. It is a practice that is used all over the world, not only for agricultural lands, but also for other applications, such as airfields and highways. In agriculture, probably no other land improvement practice requires as high an initial cost as subsurface drainage. Due to the high initial investment, the landowners are justified in expecting that a drainage system will be designed and installed with a high degree of perfection to give satisfactory performance for a long period of time. Unfortunately, the knowledge is limited to solve all the problems that drainage engineers and contractors would face while designing and installing a drainage system. However, considerable progress has been made so far through research, experience and practice. The mechanics of moisture movement in the soil under various conditions have been investigated by soil physicists and the details of the phenomena are known today to help in the design of tile drain systems. Installation equipment has been developed which can make the trench and lay the drain at the desired depth and slope with much greater precision than man could have attained with his hands and a spade. At present, clay and cement asbestos tiles are being replaced by plastic drains which are inexpensive, easy to install, and give results

comparable to clay tiles. As yet, there are no specific recommendations regarding the use of filter materials for protection of agricultural drains from clogging with silt and sediment.

Silt and sediment deposition in the drains not only reduces the efficiency of a drainage system, but also shortens its life. Therefore, some protective measures should be taken to check the entrance of sediments, yet allow water to enter the drains. It will improve the efficiency of the system and prolong the life of the drains and also make them economically feasible.

There are several approaches to solve this problem. One approach would be an attempt to design drain tile with a built-in filter that would allow water to enter but at the same time check the soil particles from entering the drain in excessive amounts. Such a design would probably result in higher cost of drain tile.

Another approach may be to have a non-silting design velocity. In any such design there may be two possibilities:

1) The control of velocity, i.e., speed and direction of water flow approaching and entering the drain.
2) Some limits imposed on the maximum size of the particles that could be carried by a non-silting velocity in the drain.

Regarding the first, Willardson(41) has made a

successful effort in designing a drain using the non-silting approach and entry velocity of water to the drain. However, his design was limited only to a laboratory study and had not so far been tested in the field. Practically, the second possibility seems difficult, because the silting problem is mostly on level lands, where such a grade for a drain line is almost impossible to obtain. The use of sediment basins is a variation of this approach. The third alternate may be that of a filter material which will exclude sediment from the drain and will increase the rate of water movement into the drain. Almost every drainage engineer tackling the problem of sedimentation agrees that a well-designed filter can solve the problem of drain clogging.

The usual term 'filter', used to include all materials placed around subsurface drains, is probably a misnomer. Instead, these materials would rightly be called an envelope, which does not necessarily mean filter. The term 'envelope' also includes the foundation or base stabilization. The functions of an envelope material around a subsurface drain are generally:

1) To exclude sediment from the drain that may cause clogging;
2) To prevent sealing at drain openings;
3) To increase the rate of water movement into the drain, and
4) To serve as a stabilizing foundation for the drain.

However, as this investigation dealt with only filtering action of the various materials, the term 'filter' was considered more appropriate than 'envelope'.

At present some criteria exist for the design of gravel filters for subsurface drains. However, there are no conclusive recommendations and these need some refinements according to the specific location. Also, some gravel filters being quite expensive, drainage engineers have been using the cheaper glass-fibre materials. These new materials have given some encouraging results. However, nothing can be said about the effectiveness of these materials as yet and there is a need for more investigation. In this investigation more emphasis has been given to the filtering properties of the glass-fibre materials under different placement conditions or combinations. The specific objectives of the investigation were:

1) To develop a drainage tank model in which the field conditions around a drain could be simulated;
2) To evaluate quantitatively the relative effectiveness of different filter materials to check siltation of plastic drain pipe;
3) To evaluate quantitatively the relative effectiveness of filter materials on the inflow of water to plastic drain tubes;
4) To evaluate quantitatively the effect of shape and pattern of perforations in commercially

available plastic drains on excluding soil from and inflow of water into them;

5) To compare the composition of the sediments discharged into drain under different treatments with that of the base soil.

From the beginning it was continuously borne in mind that field conditions would be difficult to simulate exactly in the model. Therefore, the results cannot be applied quantitatively to field conditions. It must be recognized that only comparative data were sought in this study. Because of carefully controlled conditions, these data should be of help in determining the relative value of different filter materials and in determining those that are grossly inadequate. Another advantage of the laboratory study is that data can be obtained in a shorter time than would be required in a field study. However, less time has a definite disadvantage in that neither the effect of time on filter clogging, nor on development of a natural filter by gradation can be evaluated due to the short length of test run.

Chapter 2
REVIEW OF LITERATURE

A thorough review of published literature shows that any experimental work performed on the subject of drainage envelopes has been only during the past fifty years. However, every researcher on tile drainage since the installation of the first tile drain in 1835, on the Johnston farm in New York State(34), has recognized the problem of drain siltation. Most research workers have their own opinion on how to solve this problem, while others have simply adopted the recommendations of previous workers. In the absence of extensive experimental research and data, there is nothing conclusive about the design and laying of filter materials for agricultural drainage. Only in the last twenty years have agricultural research scientists and drainage engineers recognized the need for development of criteria for the design and quantitative evaluation of the effects of filter materials on the prevention of drain tile clogging.

2.1 Conditions Requiring Filter

Alluvial soils consisting of large percentages of file sand or coarse silt tend to be unstable. Soil particles of these groups lack cohesion and are sufficiently small to be moved by low velocities of flow. Also, these soils become unstable with increasing uniformity. Nelson(28) has described the group of soils that are most

unstable as those lying within the size ranges of 0.05 to 1.0 mm. The use of filter materials is almost universally recommended in such areas. According to Brownscombe(4), textural classes alone are not always a good indication of a soil's tendency to enter and plug unprotected drains. He described plasticity and dry strength as important factors in soil stability and developed a method for evaluating the silting hazard of soils utilizing soil characteristics such as plasticity, dry strength, dilatancy and appearance in addition to soil texture. He has suggested that soils having no plasticity, only slight dry strength, rapid dilatancy and dull shine correspond to those which are unstable and likely to cause drain failure. Therefore, a need for filter is indicated for soils having these reactions. At the other end of the scale, soils having high plasticity, high dry strength, slow dilatancy and shiny appearance are stable and do not need any filter. The soils between these two limits may be hazardous, particularly if other conditions such as flow velocity and joint spacing are unfavourable. For these, judgment must be made as to their stability for the particular site and construction conditions that will prevail.

Generally, it is assumed that no filter material is needed for tile drains installed in the fine textured soils of the humid regions. This assumption is further supported by Taylor and Goins(37), who observed that in humid regions the soil adjacent to all drains was in a

porous condition, regardless of filter treatment. Apparently, this soil has water stable aggregates and consequently does not contribute significantly to siltation of the drain.

2.2 Design Criteria

Pipe drains designed and constructed for the drainage of irrigated lands should accept groundwater moving to them without a water table build-up above the drain. To accomplish this, the pipe must be surrounded by an imported material designed with a gradation and permeability compatible to that of the material being drained, known as the base material. Drainage engineers agree that for all types of subsurface drainage a large quantity of fines should not be allowed to move into the filter and the permeability must be adequate to move all groundwater converging at the joint into the pipe. However, if the envelope is to be used only for agricultural drainage, the hydraulic gradient should be low in the order of one or less. Therefore, the design criteria for agricultural drainage filters must recognize that the velocity between the base material and the envelope is low and less fines are required than for the design of protective filters for dams and canals. By reducing the amount of fines to specified gradation limitations, the permeability will be increased, which is an important requirement for a filter used for agricultural drainage. Filter gradation and permeability requirements are established on the basis of

the nature of base material encountered on a particular site.

Most investigators determined filter failure on the basis of visual observation. However, Leatherwood and Peterson(22), Livesley(24), Willardson(41), and Winger and Ryan(42) had mentioned failure of filters on the basis of change in permeability of filter material by clogging with fines from the base soil.

The following is a summary of some of the drainage filter criteria developed by various investigators.

U.S. Corps of Engineers — Sisson(34) has summarized the U.S. Corps of Engineers criteria as follows:

$$\frac{D_{15}^{*} \text{ of filter}}{D_{15} \text{ of base soil}} = \text{ or } > 5$$

$$\frac{D_{15} \text{ of filter}}{D_{85} \text{ of base soil}} = \text{ or } < 5$$

$$\frac{D_{85} \text{ of filter}}{\text{Size of pipe opening}} = \text{ or } > 2$$

In addition, a statement is made that the grain size curves of the two materials should be approximately parallel.

U.S. Bureau of Reclamation — USDA Soil Conservation Service(19) has described the Bureau of Reclamation design as follows:

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* D_{15} means that size of which 15 per cent of the particles are smaller.

$$\frac{\text{50 per cent size of filter}}{\text{50 per cent size of base soil}} = 12 \text{ to } 58$$

$$\frac{\text{15 per cent fine size of filter}}{\text{15 per cent fine size of base soil}} = 12 \text{ to } 40$$

Where both the base soil and filter material are more or less uniformly graded, a filter stability ratio of less than 5 is recommended.

Thus:

$$\frac{\text{15 per cent fine size of filter}}{\text{85 per cent fine size of base soil}} = \text{ or } < 5$$

In addition, the gradation curve of the filter material should approximately be parallel to that of the base soil. The maximum size of the filter material should be about 3 inches and there should not be more than 5 per cent of the filter material passing the No. 200 sieve. The drainage filter should be from 3 to 6 inches thick.

Close scrutiny of these drainage filter criteria reveals that no one investigator had made definite recommendations. For this reason, these criteria have been modified to make them more workable. A major forward step in this aspect has been taken by the Soil Conservation Service(19) of the State of Washington. Using a modification of the Bureau of Reclamation and Corps of Engineers filter criteria, specific design requirements were computed for gravel filter. Mechanical analysis of various soil series have been made and then these design criteria have

been used to determine the satisfactory limits for the gravel filter for each soil. In addition, mechanical analysis of available gravel filter materials have been made, thus making it convenient for the field engineers to select the proper filter material for the soil in question. The Soil Conservation Service(27) has adopted virtually the same filter criteria nationally as was developed by the State of Washington. The Highway Research Board(36) and Cedergren(5) have also mentioned and verified the U.S. Corps of Engineers design criteria.

Most of the design criteria mentioned above were developed primarily for protective filters for subsurface drainage of dams and other earth structures. But these have also been used for agricultural drainage successfully. However, during the past 20 years, some criteria have been developed primarily for the design of agricultural drains. Evans(8) has developed an envelope curve defining the lower limit of standard deviation of filter material for a given ratio of filter to aquifer median diameter. He suggested that the standard deviation of the filter material must be at least equal to the minimum taken from the envelope curve. Winger and Ryan(42) have developed the criteria based on coefficient of uniformity and coefficient of curvature for the material being used as a filter. They made the following recommendations:

Gravel:

Coefficient of uniformity = or $>$ 4

Coefficient of curvature = 1 to 3

Sand:

Coefficient of uniformity = or $<$ 6

Coefficient of curvature = 1 to 3

Lower limit for D_{60} size of envelope = 2 to 6 mm.

Upper limit for D_{60} size of envelope = 10 to 20 mm.

In addition, they have mentioned that 100 per cent should pass the 1½ inch clear square sieve opening and not more than 5 per cent should pass the No. 50 U.S. Standard Series screens.

Another factor of importance in the use of gravel filters is the degree of compaction. The Corps of Engineers (16) have recognized the value of compaction and have made a statement, that "....any filter for drainage purposes should always be packed densely. Such packing will not be achieved if moist sand and gravel is merely dumped into the drainage ditch." Nearly 20 years later, Guillou(10) comments, "...it appears that initial compaction of the filter sand is the dominant factor influencing filter stability." There are no known design criteria for other mineral filter materials, but the gravel filter criteria should apply.

During the last decade, attempts have been made to use glass fiber materials as filters for underground drains. There is some record of research to develop the

design criteria for this material to meet the requirements of an ideal filter. Nelson(28) was the forerunner in evaluating glass fiber filter materials. In his report, he has given a size distribution curve showing the soil size limits that the glass fiber filter will and will not protect. Shull(32) has evaluated hydraulic characteristics of glass fiber materials and found that when glass fiber material of one inch thickness was compressed to as little as 0.1 inch, the hydraulic conductivity was still sufficient to make a satisfactory filter. In later studies, Shull(33) tested the soil filtering properties of three glass fiber mats of thicknesses 0.1, 0.2 and 0.3 inches. He observed that soil particles larger than very fine sand did not easily move through glass fiber mats of the types tested.

2.3 Past and Present Field Practices and Recommendations

Since the time of installation of the first tile drains, there have been experiences of clogging of the tiles with silt and sediments. During this century, most of the drainage engineers have recognized this and the need for some special material around the drain to prevent clogging. For example, Janert(18) in 1933 observed the clogging problem in Germany and had made the following statement:

> "In heavy soils, particularly those containing iron, the joints get blocked up and precautions must be taken by putting a layer of some permeable matter, slag or gravel, over

> "the tiles. Such a permeable layer serves as a filter and protects the joints. Similar precautions are necessary in silty soils which are very difficult to drain as the silt passes with the water into the drains where, unless there is a very strong current, it sediments and soon fills up the drain completely. Here again something like a filter is needed but slag and gravel is too coarse to retain the fine silt."

Weir(39) first recommended either straw or gravel as an effective substance to prevent packing too closely about the drain in heavy soils and sediment entrance into the tile where quicksand is encountered. But then, ten years later he stated(40) that, "One should not use straw or brush around a tile line," and suggested a strip of about 6 inches wide tarred paper over the top half of the tile before placing gravel. Many of the recommendations during the period 1940-60 on checking of siltation of subsurface drains are almost the same. Almost all of the writers (9, 11, 30 and 36), have suggested the use of all or any one of burlap, straw, tar paper, coarse sand and bank run gravel as a filter material.

It is of interest to know the methods of protecting underdrains from siltation in various countries of the world. Juusela(20) in Finland found that in clay soils, gravel acts as a very efficient filter preventing silt from entering the pipes and says, "A gravel filter is always recommended." Livesley(24) states: "In Sweden and Denmark tiles are first covered with varying depths of fine top soil before being back filled." Eriksson(7) in

Sweden has recommended various thicknesses of gravel, sawdust and glass mat, as an envelope for the underground drains. Hooghoudt(13) has discussed drainage in The Netherlands, stating that frequently coarse peat dust is used to prevent soil particles from entering into the tile. Sisson(34) had conducted a survey of Midwestern States of the U.S. regarding drainage filter practices. Here is the summary of his findings:

> "Most of the states use a filter material of one kind or the other. The materials used are impregnated glass fiber sheet, burlap, tar paper, gravel, straw, hay and cinder, etc. Some of the states also recommend a minimum grade of 0.07 per cent."

To determine the present practices in different Canadian Provinces on the use of drainage filters, a survey was conducted. The questions were asked of drainage experts about the recommendations, if any, regarding the use of filter materials, grades and size of plastic pipes used for subsurface drainage. Following is a summary of the findings.

Alberta(31). It is generally recommended that the tile drain be surrounded by approximately one foot of pit run gravel to provide both a stable base and to ensure stability of the surrounding soils. A minimum size of 4 inches is recommended for plastic pipe lateral and generally the minimum preferable grade is 0.002 but on some major interceptors grades have been as flat as 0.001.

British Columbia. Baehr(1) states:

> "Our recommendations for filter material in problem soils is to provide a 6 inches thick envelope of cedar shavings over and around the tile. If very serious conditions exist, we recommend a complete filter including underneath the drain, or a closed conduit."

Manitoba(21). Since agricultural drainage has not been practiced extensively in the province, there are no specific recommendations regarding the use of drainage filters.

Ontario. Irwin(17) states:

> "The use of subsurface drains for irrigation is minimal; however, they are used substantially for general drainage purposes in the province. We also use about 14 million feet of glass fiber material annually for filtering purposes. They are generally associated with our problem sandy soils."

The minimum recommended(6) grades for drains are as follows:

4 in. drain . . . . . 0.10 ft. per 100 ft.

5 in. drain . . . . . 0.07 ft. per 100 ft.

6 in. drain . . . . . 0.05 ft. per 100 ft.

While laying drains in sandy soils, it is recommended to cover the upper two-thirds of the drain joint with a glass fiber filter material or tar impregnated paper (such as saturated #2 tar paper).

2.4 Previous Research

Some field as well as laboratory research has been conducted to evaluate the effectiveness of various filter materials under various types of soils and placement conditions around the drain. Most of the research records

of the last two decades are for tile drains. Research on cover materials for corrugated plastic drains has been carried out only during recent years and no significant records are available.

Overholt(29) was among the leaders in conducting research and evaluating glass fiber filter materials. He found, in a laboratory study, that glass fiber sheet (tile guard which has a thickness of about 20 mil) was effective in reducing the rate of siltation of tile lines in a sandy soil and in increasing the rate of water flow. Silt accumulation in unprotected tiles was 3.49 times greater than in tile where the top three-fourths of the circumference was covered with glass fiber sheet. Where glass fiber sheet was wrapped completely around the tile, the filter gave almost complete protection against silting. From the same tests the rate of water discharge was 1.7 and 2.26 times greater, respectively. In 1959, Sisson(34) conducted a laboratory study comparing several different filters and envelope materials. Straw and sawdust were found relatively effective in preventing sand from filling tile. Straw, top soil, and sawdust gave no significant difference in water discharge rates into the drain tube, but a gravel envelope gave a significantly greater rate of water discharge than these other materials. Hore and Tiwari(14) reported in 1961, a laboratory comparison of various combinations or placement conditions of two glass fiber cover materials: Duramat and tile guard. Based on

the relative effectiveness of various treatments on the movement of soil and water through the tile joint into the drain, the treatments were rated in the following order:

1) Tile guard above and below the drain.
2) Tile guard above and Duramat below the drain.
3) Tile guard on top three-fourths of drain only.
4) Duramat on top three-fourths of the drain only.
5) Blinding with top soil.

The only study evaluating the effect of time on organic material was reported by Brownscombe(3) in 1962. He found straw deteriorated slightly to moderately after 6 to 11 years and wood chips showed little sign of deterioration after 9 years. At about the same time, Hudson and Hopewell(15) reported on methods of backfilling of tile trenches in clay soils. Backfilling material included clay, turf, gravel and straw. Continuous records for 8 years showed no difference in outflow and it was concluded that appreciable expense for special backfilling materials in clay soils was not warranted.

In 1963, Hansen(12) made a comparative study of the grain size characteristics of gravel material used as filters with the existing soils at respective sites and glass fiber material. It was noticed that the filter material being used in subsurface drains in Vermont was too fine and that the glass fiber could be used as an effective filter at a reduced cost. In 1964, Lyons(25) reported on a field study comparing safflower straw, glass

fiber mat envelope, and no envelope. In comparing rate of water discharged, the safflower straw gave the best performance. Glass fiber mat was less effective and the lines with no envelope ranked last. This study was in a muck soil with a reputation of sealing the joints of the tile drain and making them ineffective.

Skov(35) in Denmark had compared 12 mm glass wool band and 0.7 mm enforced glassfelt wrapped completely around clay and plastic drain pipes with unpacked pipes. He observed that the conductivities of clay pipes and of plastic conduits which were packed with glass wool were on the same level. The conductivity from the glassfelt packed and unpacked plastic conduits were, however, considerably lower and after 2 years the passage of water through these pipes had almost ceased. Meanwhile, the water passage from the glass wool packed plastic conduit was also decreased considerably. In all unpacked conduits, sand was deposited in varying quantities. The packed conduits on the other hand were clean.

In 1969, Lembke and Bucks(23) conducted a model study on the performance of the drain without an envelope and with gravel filter of two thicknesses for a square placement around the drain. Both three and six inches gravel envelopes performed successfully in the model with no noticeable base material in the tile effluent while immediate failure occurred in the test with no envelope. They found that the top corners of a rectangular gravel

envelope were particularly subjected to intrusion by fine particles.

Chapter 3

MATERIAL AND PROCEDURE

3.1 Selection and Description of the Base Soil

Most of the literature reviewed indicates that the coarse silt and fine sand are the most unstable soils. The soil particles of these sizes lack cohesion and are small enough to be moved by a low velocity of water to cause quick condition. Therefore, the hazard of tile clogging is most common among these soil groups. Nelson (28) has described the soil groups between 0.05 and 1.0 mm as most unstable. It has been common practice to base the need for filters on the texture and general appearance of the subsoil at tile depth. But textural classes alone are not always a good indication of a soil's tendency to enter and plug unprotected drains. Characteristics such as the plasticity and dry strength are known to be important factors in soil stability.

In the Edmonton area most soils range from sandy to clay loam in texture, so originally it was planned that at least two types of soils would be used as base material. However, as the number of treatments proposed were many and also plastic drain tubing with two types of perforations was being used, the time available made it necessary to either study only one soil or to reduce the number of treatments. After all necessary considerations regarding the problem, it was felt that a study of a number of filter

materials on one base soil was a better alternative. Thus, it was decided to use only one type of soil that is prevalent or at least closely related in its characteristics to the prevalent soil types.

In selecting the base soil, the primary consideration was not only that the soil would present a very serious drainage hazard, but also that it should be representative of the area. Verma(38) has classified some of the soils around Edmonton and his classification indicates that most of the soils in this area are medium textured rather than light textured. As no drainage is practiced in this area, there was no data available regarding the hazard of clogging and failure of drains due to this cause. Therefore, it was decided to carry out mechanical analysis and Atterberg limits tests on some representative soil samples of the area to determine the need for filter material on the basis of the previously established criteria. Since there was some special interest in the soil of the University of Alberta Ellerslie farm, it was considered more appropriate to take samples from the Ellerslie farm to carry out the required tests. Three sites were selected for sampling purposes on the Agricultural Engineering section of the Ellerslie farm. The samples were taken from the top foot and the third foot of the soil. The mechanical analyses were performed on the samples and plotted as shown in figure 3.1. To determine the filter requirements on the basis of criteria set by Brownscombe(4),

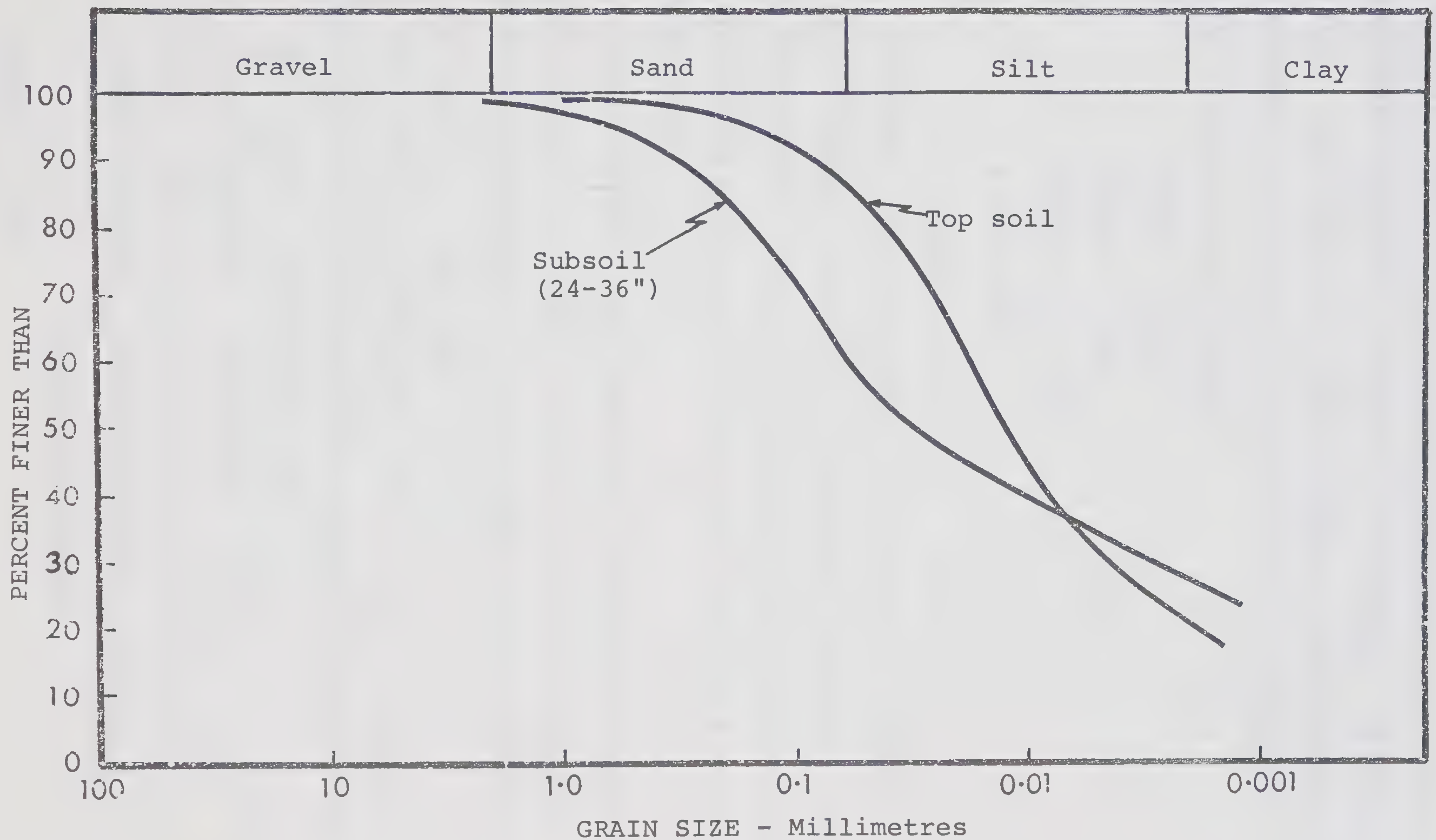


Figure 3.1. Grain size distribution of the base soil

Atterberg limits tests were performed and the soil was classified according to Unified Engineering classification system. The results of the Atterberg limits tests and description of soil on the basis of the engineering classification is as follows:

Liquid limit 46%

Plastic limit 30.2%

Plasticity Index . . . 15.8%

Flow Index 7.4%

Toughness Index . . . 2.135

The soil falls in the soil groups of ML and OL. The soil has slight to medium dry strength, is low in dilatancy and has slight toughness. Organic silts and organic silt clays of low plasticity having rock flour and fine sands are present.

The results of the mechanical analysis and Atterberg limits tests gave some indication that the problem of siltation would exist if underground drainage would ever be practiced in this area.

This soil falls(2) under the general category of Ponoka loam and its general description is as follows:

Soil type - Ponoka light loam

Classification - Chernozemic

Area - University of Alberta, Ellerslie farm

Parent material - Medium textured, alluvial lacustrine material

Relief - Flat

Horizon	Depth	Description
Ah	0-18"	Black to very dark brown loam, weak prismatic to granular; may vary from 12 to over 20 inches in depth.
Ahe	18-20"	Greyish brown to brown loam to silt loam; weak platy.
Bt	20-28"	Yellowish brown loam to clay loam, weak columnar to weak subangular blocky, friable. Some slight organic staining on the surface of the peds.
Bm	28-40"	Brown to yellowish brown loam to clay loam; weak prismatic to weak subangular blocky, friable.
Ck	40"+	Dark yellowish brown sandy loam to clay loam; massive; friable; lenses of coarse and medium textured material.

Verma(38) measured the field bulk density of the soils in the Edmonton area to a 4 ft. depth. His results showed some variation in field bulk density at different locations and also a density gradient with depth. Since the bulk density of the soil varies from point to point, it was considered better to use the average of bulk densities found by Verma(38) for similar type of soils as the base soil. According to his results, the density gradient in the soils similar to the base soil is shown in figure 3.2.

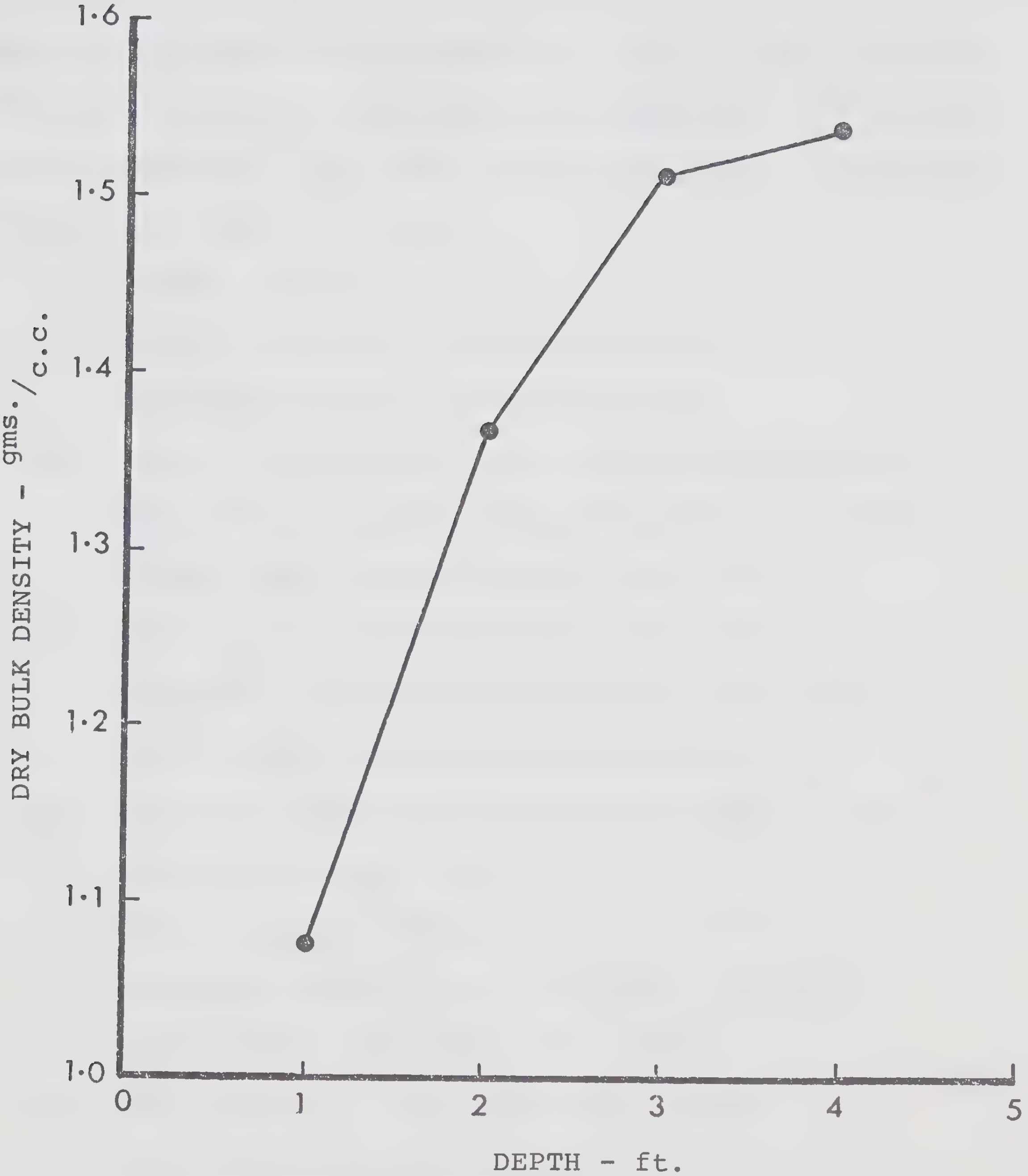


Figure 3.2. Field bulk density gradient

3.2 Description of the Filter Materials

Seven filter materials or combination of materials were used in this investigation. An eighth condition of no filter material was also included so that the relative effect of different filter materials to no filter condition could also be studied along with the comparison of different filter materials. The seven filter materials or combination of materials were as follows:

1) Gravel filter.
2) Glass fiber mat over the top three-fourths of the drain (Glass fiber mat 270°).
3) Glass fiber mat over the top three-fourths of the drain and glass fiber felt below the drain (Glass fiber mat with glass fiber felt).
4) Glass fiber mat over the top three-fourths of the drain and poly-underlay below the drain (Glass fiber mat with poly-underlay).
5) Tile guard over the top three-fourths of the drain (Tile guard 270°).
6) Tile guard over the top three-fourths of the drain and glass fiber felt below the drain (Tile guard with glass fiber felt).
7) Tile guard over the top three-fourths of the drain and poly-underlay below the drain (Tile guard with poly-underlay).

The major emphasis in this investigation was on the different kinds of glass fiber materials manufactured for

this purpose, this being due to the fact that little research work has been done on these materials and still more investigation is needed. Other materials like the gravel filter have been under investigation for the last three decades and the criteria for their design and functioning are well established. However, due to higher costs and inconvenience in the handling of gravel filter and less life expectancy of organic filters, the trend is presently toward the inexpensive glass fiber materials which are also easy to handle.

The following is the detailed description of the materials used.

1) Gravel. The required filter design was based on U.S. Bureau of Reclamation(19) and Winger and Ryan(42) criteria. The upper and lower limit grain distribution curves of the required filter were drawn for the selected base soil. An ideal gravel filter should fit midway between the upper and lower limits of the designed filter.

The grain size distribution of the gravel used as filter material is shown in figure 3.3, and makes a good fit. The maximum size of the gravel was $^3/_4$ inch, and the uniformity coefficient was 13.3.

2) Glass Fiber Mat. Glass mat type W-85-10-20 is a jack straw arrangement of glass fibers of uniform diameter, reinforced across the sheet with staple fiber slivers in longitudinal direction, spaced $1\frac{1}{4}$ inches apart, all

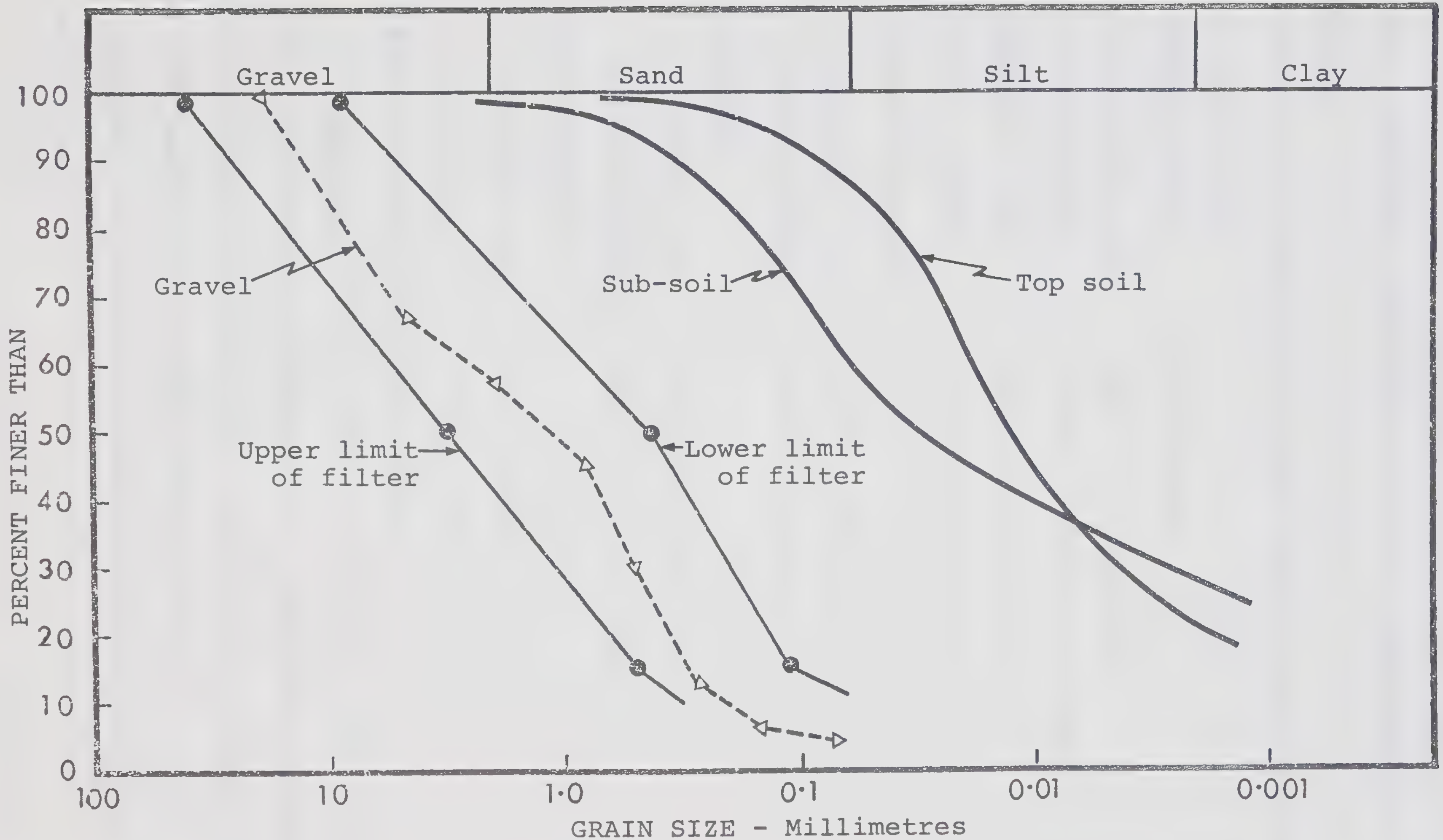


Figure 3.3. Grain size distribution of base soil and gravel filter

bound together with a resinous thermosetting binder into a tough, porous mat for conversion into tapeshield and outerwrap.

Physical and mechanical properties of the glass fiber mat are as follows:

Width of mat . . .	12.00 inches
Thickness of mat .	0.014 $\pm$ 0.002 inches
Fibre diameter . .	0.00050 $\pm$ 0.000055 inches
Weight of mat . .	0.85 lbs/100 sq. ft.
Type of binder . .	Urea-Formaldehyde
Tensile strength -	
along the roll .	18.5 $\pm$ 2.00 psi
across the roll	10.00 $\pm$ 1.00 psi
Extension -	
along the roll .	1.00 $\pm$ 0.2 per cent
across the roll	1.00 $\pm$ 0.2 per cent
Tear strength -	
along the roll .	290 $\pm$ 30 gms
across the roll	600 $\pm$ 60 gms
Burst strength . .	40 $\pm$ 4 psi

3) Tile Guard. Tile guard is a porous glass fiber mat, felt-like material composed of a jack straw arrangement of individual filaments of glass fibers bonded into a uniform sheet with a thermo setting resin.

Physical and chemical properties of the tile guard are as follows:

Type of glass - lime borosilicate

Nominal thickness - 0.20 inches

Diameter of glass filament - 0.00055 inches

Weight of mat - 1.05 lbs/100 sq. ft.

Type of binder - phenol-formaldehyde

Percentage binder - 18 per cent

Width of mat - 12.00 inches

4) Glass Fiber Felt. The glass fiber felt has the same physical and chemical properties as the tile guard except for the weight per 100 sq. ft. of mat is approximately 0.76 lbs. unsaturated, has parallel glass reinforcing strands every ¼ inch, and the finished product is saturated with 210^{o}F melt point blowing roofing asphalt and dusted with ground mica and sand mixture to keep it from sticking within the roll.

5) Poly-Underlay. Poly-underlay is a regular polyethylene sheeting and it comes in 2 mil. thickness for use under plastic tubing. The 2 mil. has approximately 88 sq. ft. per lb.

3.3 Construction of Drain Tank Model

It was decided that the drain tank model should meet the following requirements:

a) It should be of such a size that a large number of test runs could be made conveniently with a minimum of labour and available facilities.

b) It should be of such minimum dimensions that certain field conditions could be simulated to

some reasonable extent.

c) It should permit both saturated and partially saturated flow conditions through the profile.

d) It should have design features which make the filling and emptying operations easy.

The tank was constructed of 3/4 inch plywood. To allow flexibility in performing tests, four identical tanks were constructed. To provide the necessary strength, the tanks were constructed in a $1\frac{1}{2}$ - 3/16 inch angle iron frame. The schematic sketch of the completed tank is shown in figure 3.4. The inside dimensions of each tank were: 48 inches deep, 18 inches wide, and 12 inches long. All permanent joints were secured with waterproof glue and wood screws. For visual inspection of the soil profile during the test run, the front panel of each tank was made of plexiglass. The front panel had a joint in the middle, which was provided with a rubber gasket to check excessive leakage. The upper half of the panel was removable. This feature was provided for convenience during filling and emptying operations.

Corrugated plastic drain tubing of four inches inside diameter and four and one half inches outside diameter was used. Two types of drains used were identical in material and shape, but had different shapes of perforations. One type of drain had three slots of about $1\frac{1}{4} \times 1/8$ inch each, 120° apart around the periphery, while the other had eight identical holes equally spaced

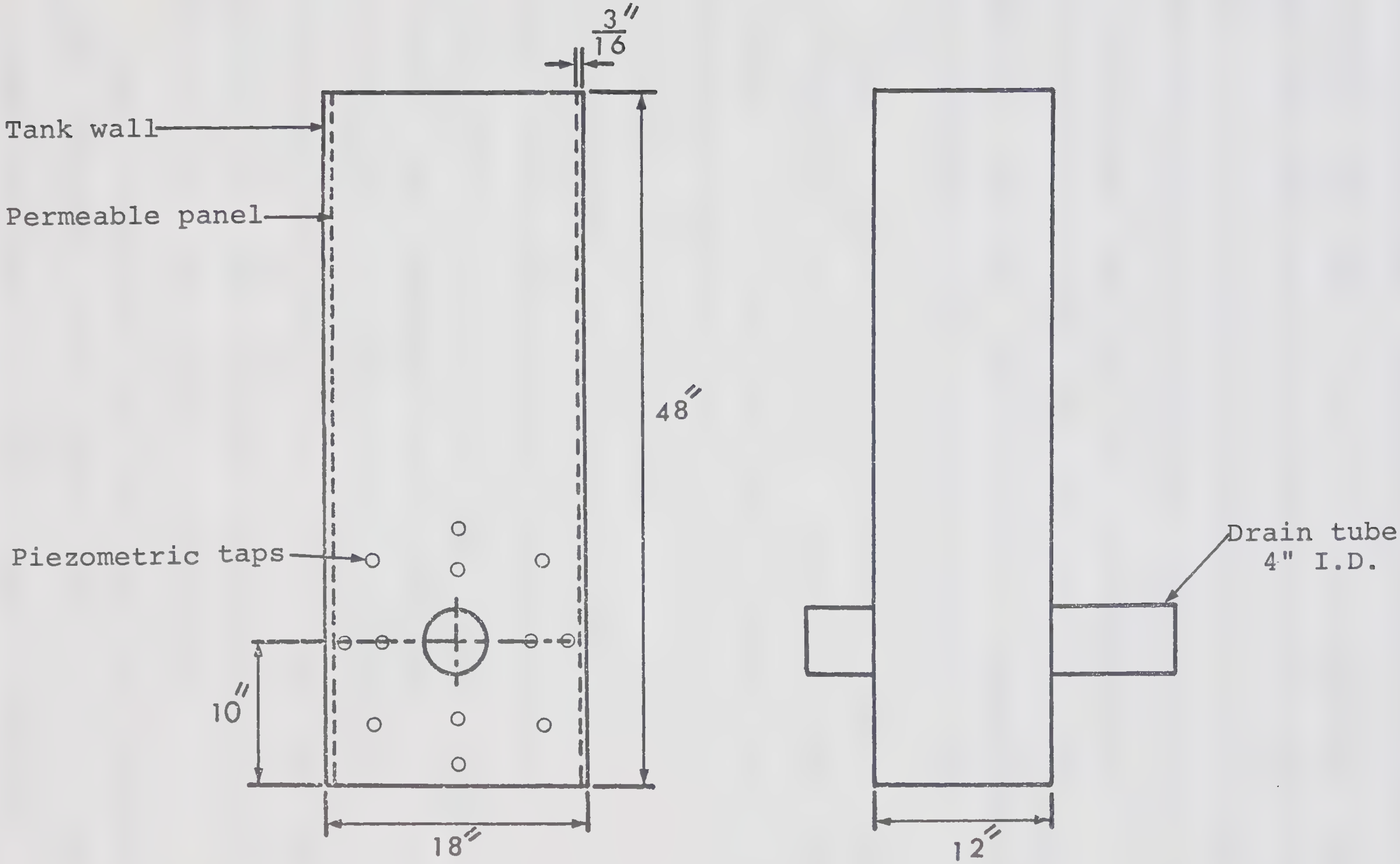


Figure 3.4. Schematic diagram of drain tank

around the periphery. Each type of drain was fixed in two tanks. The centre line of the drain tube was located about ten inches above the bottom of the tank symmetrically across the 18 inch width. The back ends of the drains were made watertight with the help of end plugs and epoxy. The drains were fixed into their position by using epoxy and were extended about six inches from the tanks toward the front end. The holes in the extended portion were sealed with epoxy to prevent leakage of water.

The tank depth of 48 inches was selected to simulate four feet of the soil profile. However, the total depth of the soil in the drain tank was 45 inches, the top three inches being discarded. Depth of soil cover over the top of drain tube was about 33 inches.

As mentioned earlier, the drain tank model was designed to simulate a complete drainage cycle for saturated field conditions just after heavy irrigation or rainfall and unsaturated field conditions. A $^3/_{16}$ inch wide gallery was provided on both sides from bottom to top along the 12 inch side of the tank. The galleries were created by inserting a water permeable panel along the inner side of the tank wall.

These panels were built from $3/_{16}$ inch perforated asbestos sheets by placing three layers of glass fiber mat between two sheets and holding them in position by screws. The screws were projected $^3/_{16}$ inch toward

the tank wall and so held the panel $^3/_{16}$ inch away from the wall when the tank was filled with soil. To simulate unsaturated flow conditions in the field, the water was supplied to the tank through these galleries. To keep the water level constant in these galleries, an overflow was provided. This arrangement of water application for unsaturated flow conditions was thought to be closer to field conditions rather than applying water from the top. However, for saturated flow conditions, the water was directly applied to the soil surface in the tank. The drain tank was designed to provide approximately two inches of ponded water during the saturated phase of the drainage cycle.

Twelve piezometric taps were provided around the drain in a six inch radius. These taps were provided with sieves to prevent flow of soil particles through them.

3.4 The Experimental Apparatus

It was decided that the soil moisture flow conditions to be used in the tests were to simulate actual flow conditions in the field as nearly as possible. Using ponded water, saturated flow only was deemed not sufficient. The decision was made that two different flow conditions were to be used:

1. Ponded water - saturated flow.
2. Partially saturated (unsaturated) flow.

A flow cycle was designed that was comparable to the actual drainage cycle in the field. The first half of

the test run would be the ponded water, saturated flow condition, to simulate conditions just after a heavy irrigation or rainfall, and the second half of the test run would be partially saturated. The total length of the run was arbitrarily chosen as five hours, with each flow condition being maintained for two and one half hours always in the sequence mentioned above.

Water was applied to the soil surface during the ponded water flow conditions. The rate of flow from the reservoir was adjusted with gate valves in such a manner that about 2 inches of water was always standing on the soil surface in the tank. During ponded water flow conditions, the water inlet and the water overflow pipe on the side of the tank were connected to each other by a tube to check the flow of water through them. During the partially saturated flow conditions, the water to the soil column was applied through the galleries provided at both sides of the tank. A constant water level was maintained in the galleries with overflow tubes. With this rate of application, there was no water standing on the soil surface.

A flow diagram of the experimental apparatus is shown in figure 3.5. A constant head tank shown in figure 3.6 was used as a water reservoir both during ponded and partially saturated flow conditions. Water for the system was furnished from the University supply line. No difficulty was experienced in regulating the flow to the desired

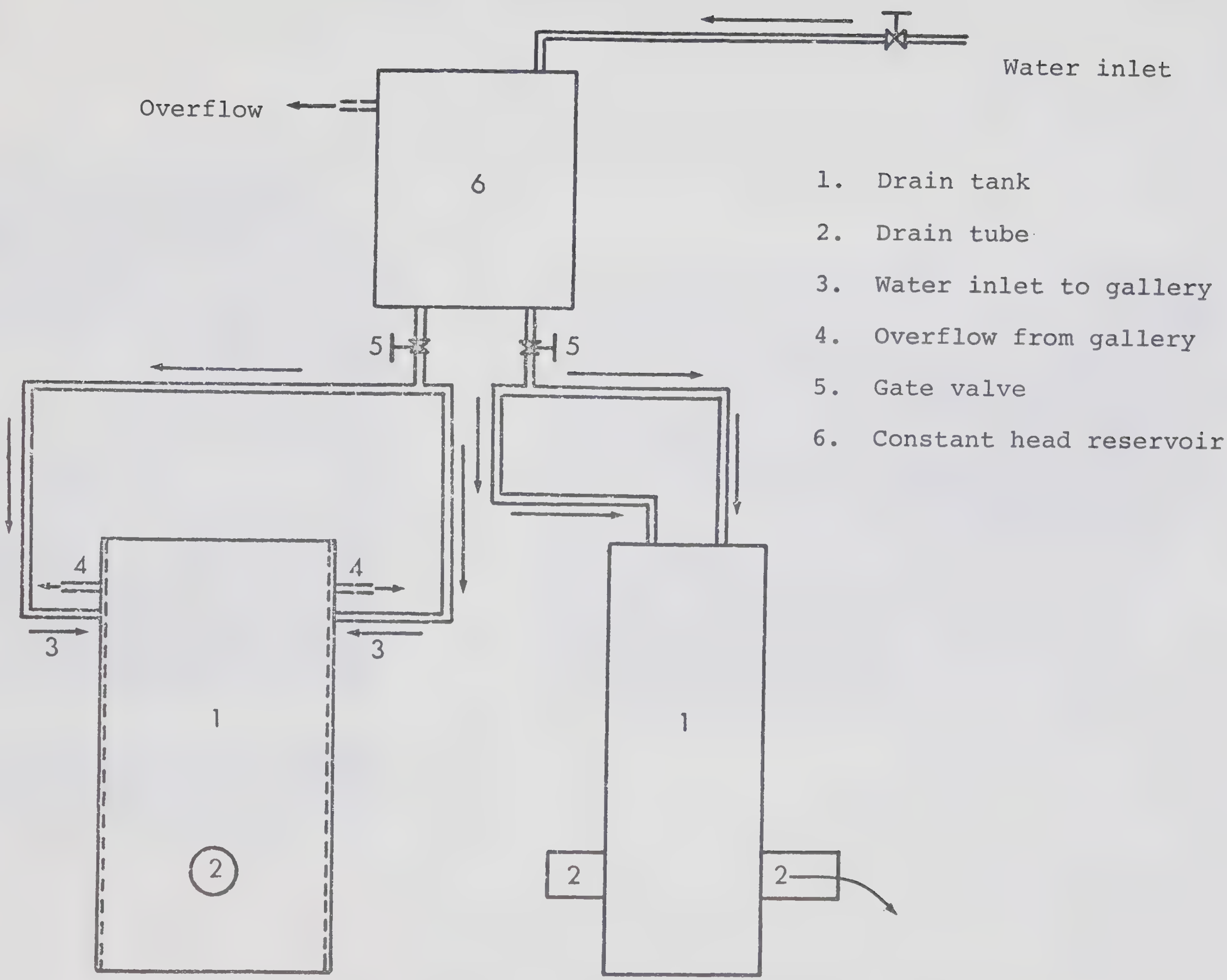


Figure 3.5. Schematic diagram of apparatus & flow system

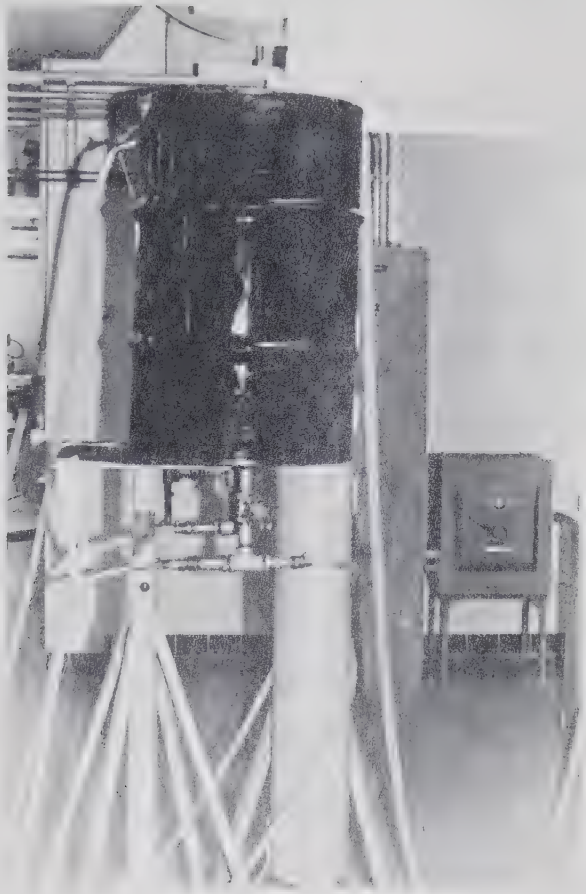


Figure 3.6. Constant head water reservoir

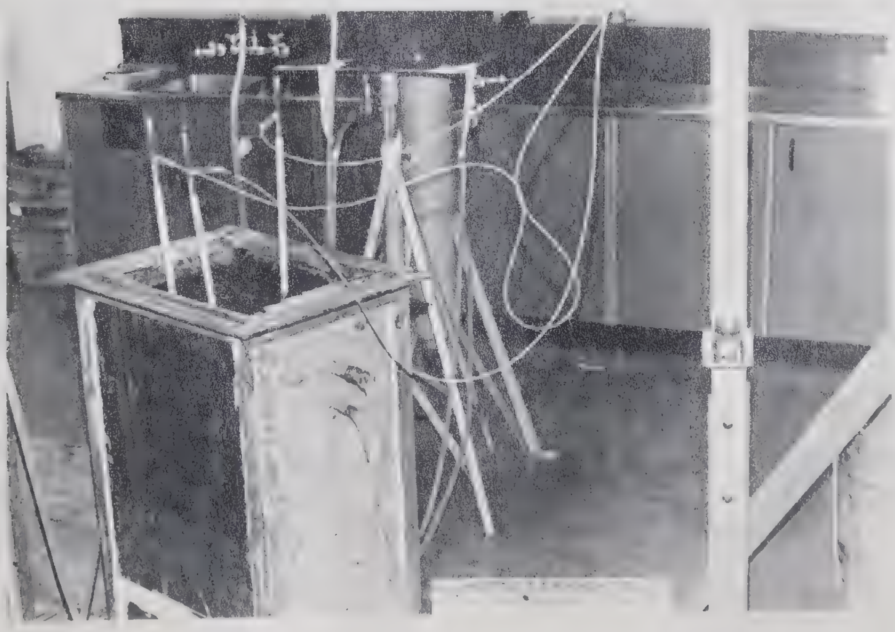


Figure 3.7. Experimental set-up

rates.

In the absence of any subsurface drains in the Edmonton area, there was no information regarding the potential head existing around the drains under field conditions. As only comparative data was desired, it was not necessary to maintain the same potential around the drain as in the field. However, to measure the pressure head existing in the drain tank model, piezometric taps provided around the drain were connected to the manometer board.

To measure the suction head in the soil profile during the unsaturated flow conditions, three tensiometers were installed in each tank at different depths as shown in figure 3.8. These tensiometers were made in the laboratory in accordance with the procedure explained by McLean(26). Figure 3.9 shows a complete tensiometer. The tensiometers were connected to the mercury manometer shown in figure 3.10 to read the suction head.

3.5 Experimental Procedure.

New base soil was used for each test run. This was necessary because it was planned to fill the tank with four feet of soil column as close to the field conditions as possible. This would have been difficult, if not impossible, with the same base soil being used repeatedly. Also, during each test run some of the fine fraction of base soil would have been washed out, thus changing the soil texture.

A question of major concern was how to maintain the

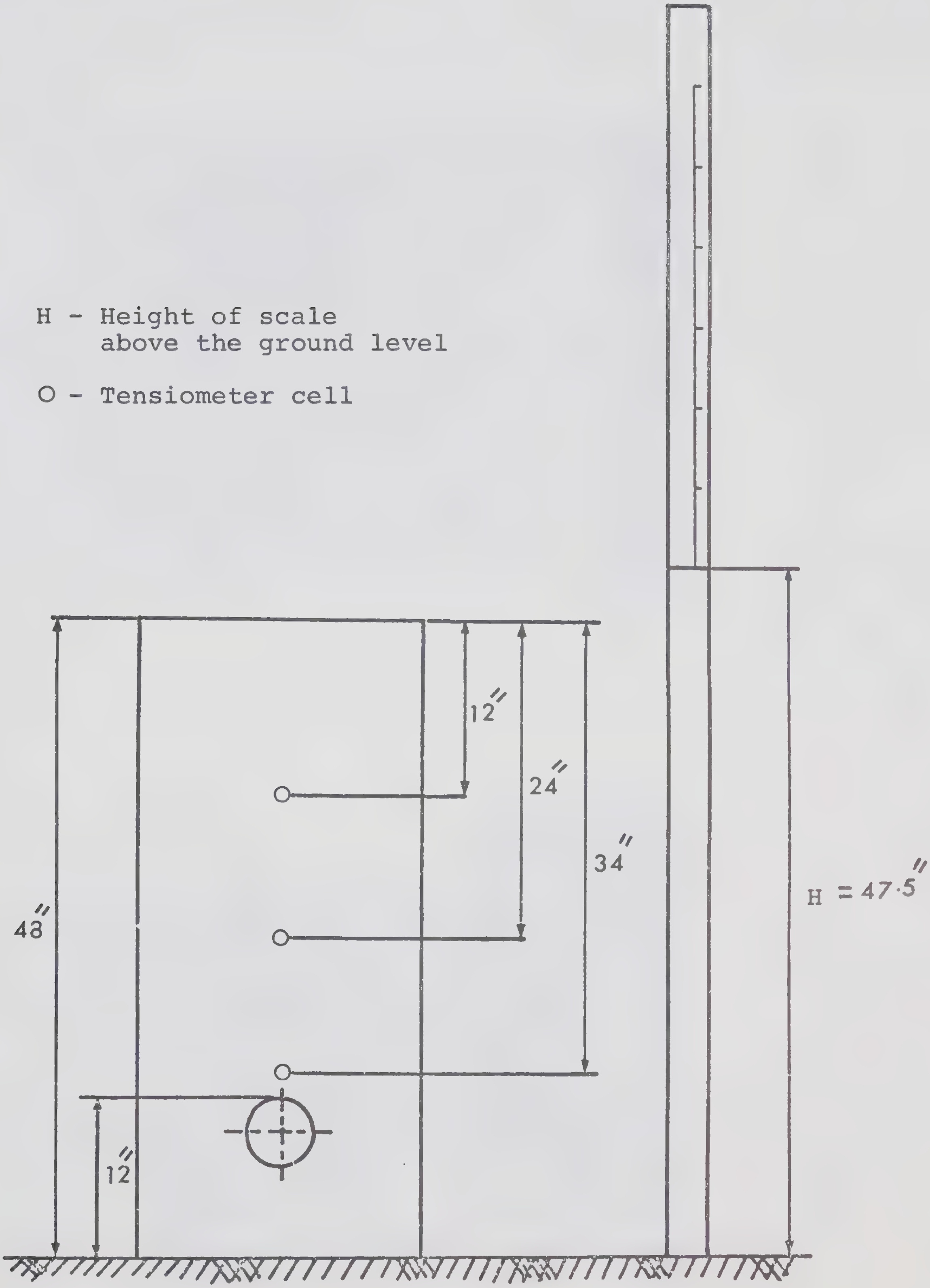


Figure 3.8. Sketch to illustrate the depth of tensiometer cells in the drain tank

Figure 3.9. Tensiometer

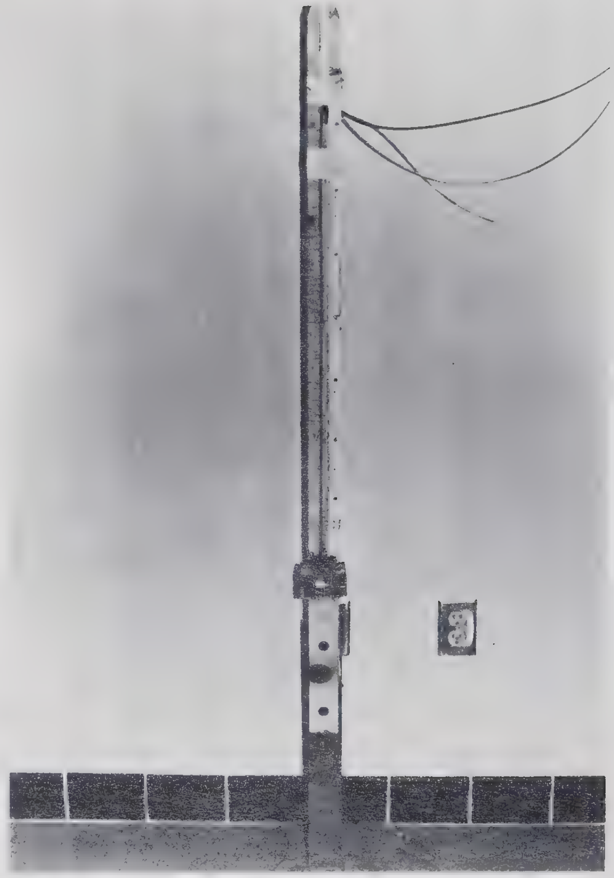


Figure 3.10. Mercury manometer

same density gradient in the tank as in the field. Several different methods were tried. First, the soil was brought into the laboratory in barrels. It was then compacted and the quantity of soil in a known volume of different segments of the tank in layers of two to three inches was weighed. But the moisture content of the soil while in the laboratory was changing and it was difficult to find daily variations in moisture content by the gravimetric method. Therefore, this approach did not work satisfactorily. The possibility of finding moisture content by using moisture blocks was ruled out because it was not possible to calibrate the blocks due to changing soil density in each drum. In the absence of any space in which the temperature and the humidity could be controlled, it was not possible to keep the soil moisture contents at a constant level. Another approach was to take the tanks out on the site, to dig the same volume of soil from the field as the volume of tank, and to fill it in the tank maintaining the same profile sequence as in the field. This was a slow and tedious method. However, with a little practice, it worked satisfactorily. To check for accuracy and precision, two density samples were taken from each tank at random from every second foot. There was some difficulty in compacting the soil around the drain because under actual field conditions the drains are laid in a trench. The shape of the trench was difficult to maintain in the tank. However, this was not im-

portant in this study, since only comparative data were desired.

The filter materials were wrapped around the drain as mentioned previously. The thickness of the gravel envelope, limited somewhat by the dimensions of the drain tank, was three inches on each side, and above the top and bottom of the drain.

As mentioned previously, the total test run was of five hours duration, consisting of an initial two and one half hour period of ponded saturated flow, and the remaining two and one half hour period of a partially saturated flow condition. At the start of each run, the water was allowed to enter the soil surface in the drain tank at a rate so that about two inches of water remained ponded on the soil surface. However, the start of each run was from the time water first appeared in the drain tube, which usually was 30 to 45 minutes after the water was first introduced at the soil surface. The conversion from a ponded water condition to a partially saturated flow condition took about 30 minutes. After two and one half hours of a ponded water test run, the water supply to the soil column was closed and water standing on the soil surface was allowed to drain. After the ponded water was drained, the water supply to the soil column was restored through the side gallery. After the water level in the gallery reached a constant level, the partially saturated part of the cycle was started.

As wide fluctuation in the flow rate was expected in the initial stages of the cycle for ponded water flow conditions, three readings were taken for rate of flow during the initial 15 minutes. During the remainder of the initial half cycle, the rate of flow through the drain was measured at 15-minute intervals. For the partially saturated part of the cycle, the rate of flow was measured at 30-minute intervals. Total flow of water and soil discharged for the whole cycle was collected in the plastic bucket. The sediments were allowed to settle overnight and then the water was drained off. The drain tube was completely cleaned of sediments at the end of each cycle and this quantity added to the sediments discharged in the bucket during the entire cycle. The sediments were dried in an oven at $105^{\circ}C$ and weighed.

The drain tanks were emptied in the laboratory, using a small crane. The used base soil was placed in barrels and hauled to the field.

The experiment was designed as a simple factorial design. Duplicate runs were performed for each filter material, including the check. The order of performing the test was random. Data were recorded for a total of thirty-two runs. The measurements made and recorded for each run were:

1) Rate of water flow through the drain for both flow conditions.
2) Soil discharged during the entire cycle.

3) Pressure head around the drain for both flow conditions being investigated.

4) Suction head in the soil profile during the partially saturated flow conditions.

The rate of water flow through the drain was measured by using a small container of known volume and a stop watch. The time for filling of the container was noted and then the rate of flow was calculated by dividing the container volume by the time.

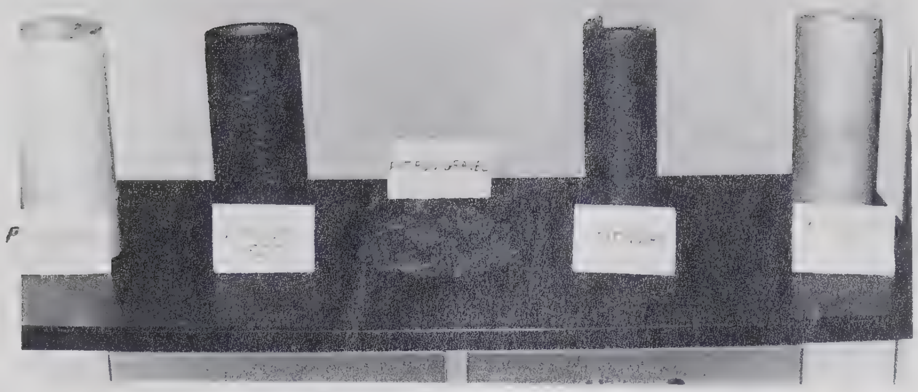


Figure 3.11. Material used in filters

Figure 3.12. Water discharge measurement

Chapter 4

RESULTS AND DISCUSSION

4.1 Bulk Density

The field bulk density and the bulk density of the base soil maintained in the drain tank model at various depths is shown in figure 4.1. It was apparent that the density gradient maintained in the drain tank was quite close to that found in the field. A slightly lower bulk density measured at the third and fourth foot in the drain tank model was assumed to be compensated by the extra pressure caused by compaction while filling the top two feet of the tank. Under field conditions density may even vary slightly within one foot of the soil profile. However, for the purpose of this investigation, the density within the range of a one foot depth was considered to be uniform.

Probably the most critical base soil density was immediately around the drain and at the interface between the filter material and base soil. The density measurements made in the laboratory do not necessarily represent the density of base soil in the critical areas mentioned. However, every effort was made to maintain the density of the base soil around the drain uniform throughout and there was no reason to believe that the density in this area was any different.

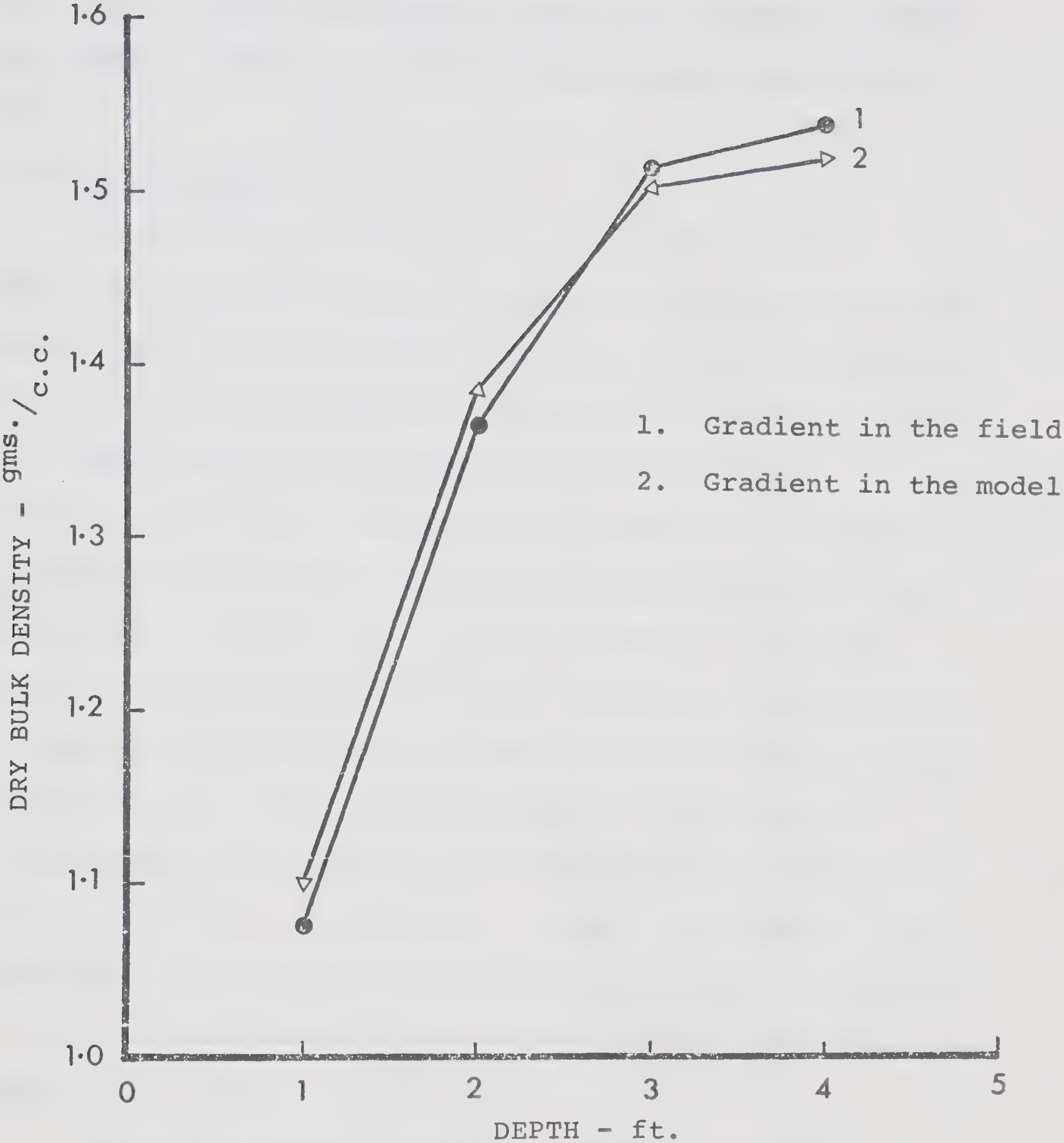


Figure 4.1. Bulk density gradient in the field and in the model

Bulk density was not of concern for filter materials used in this investigation except for the gravel filter. The gravel filter was packed firmly and uniformly around the drain. However, no bulk density measurements were made.

4.2 Soil Movement

The base soil used in this investigation was a medium textured loam rather than light textured sandy soil used by most investigators. Figure 4.2 shows the quantity of soil moved into the drain under each treatment. There is a wide range in the amount of soil discharged into the drain tube with the various filter materials. The amount of sediments discharged without any filter material was considerably greater than in the treatments with the filter material. There was some variation in the amounts of sediments discharged for same filter materials between different runs. This variation may be attributed to differences in compaction of filter material around the drain in the case of the gravel filter. For other filter materials, possibly much of this variation can be explained by the non-uniformity of pore sizes in the glass fiber material as found by Nelson(28).

Under all treatments, most of the soil movement occurred during the first half of the test period, when the ponded flow conditions existed. This observation suggests that in the field most of the soil movement will occur during and shortly after the heavy irrigation or

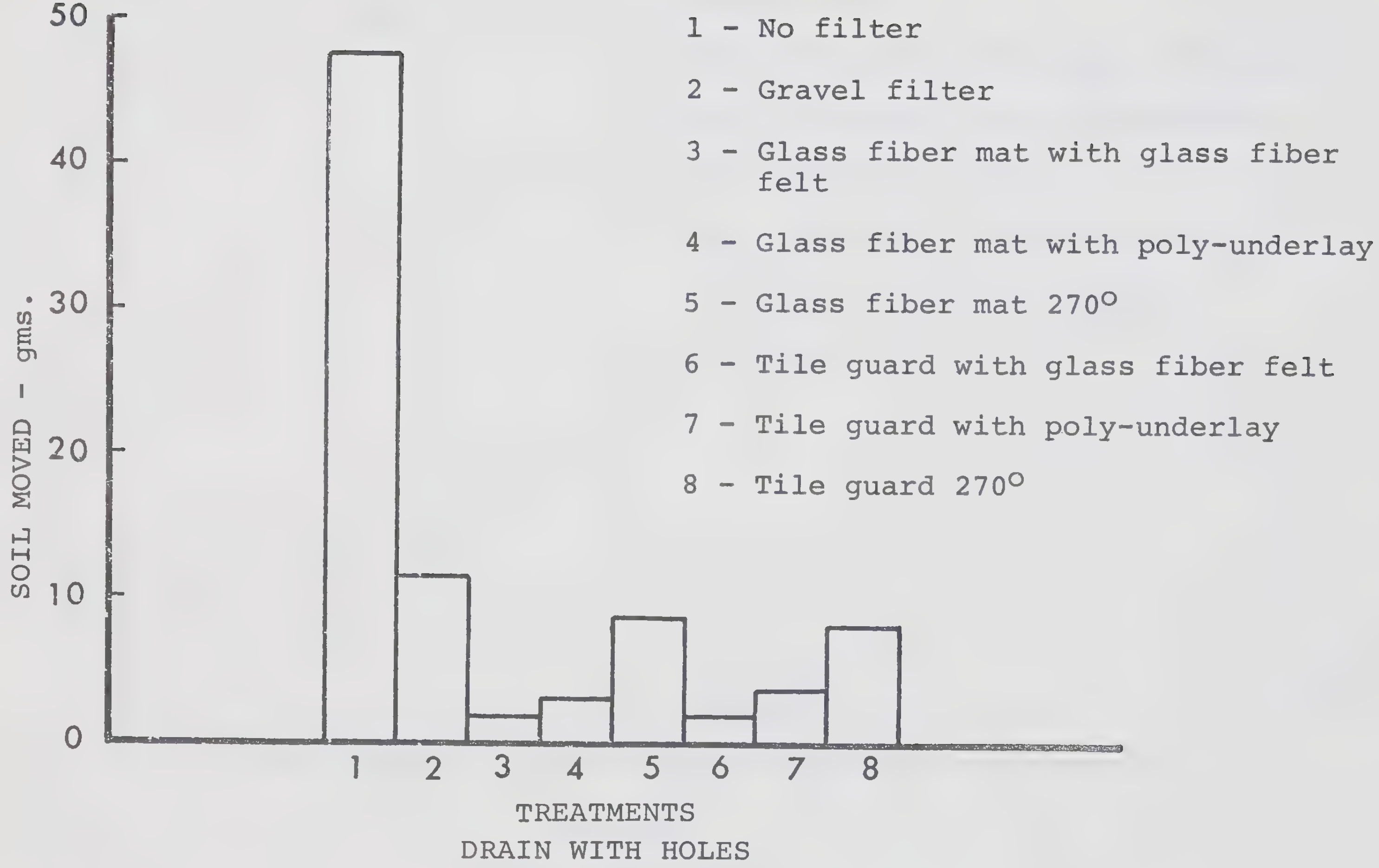


Figure 4.2. Soil moved into the drain tube under various treatments

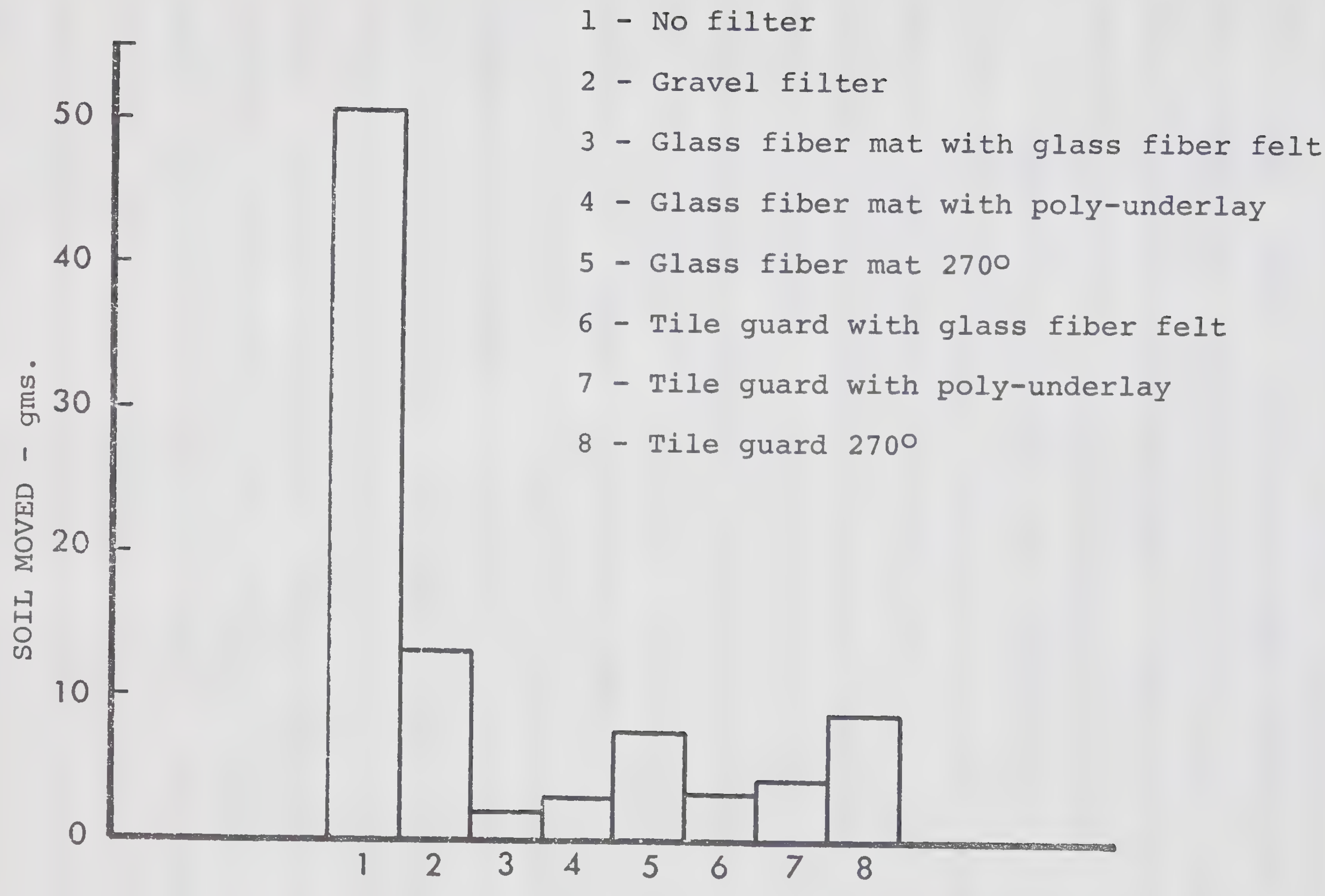


Figure 4.2. (Continued)

rainfall, rather than under equilibrium ground water conditions. However, even under ponded water flow, the soil movement was relatively higher during the initial period of the test run which may be due to the presence of more fine particles in the beginning of the test.

An analysis of variance was performed to test for significant differences of the results on soil movement. Obviously, the sediment discharge with no-filter treatment was significantly greater as compared with other treatments. Thus, in an analysis of variance, the data for no-filter treatment was not included. The procedure used for analysis was as outlined by Zalik(43), using Duncan's multiple range test for comparing individual means.

The summary of the analysis of variance of soil discharged is presented in table 4.1. The results show that the filter materials were significantly different at the one per cent level in the amount of soil discharged. However, the perforation types did not affect the sediment discharge significantly. The interaction was not a significant factor in sediment movement. The response curve for interaction between perforation types and the various treatments is shown in figure 4.3. It is apparent from the response curve that the effect of filter materials on soil discharge for different types of perforations was about the same for all filters.

An over-all comparison of averages for the sediments discharged for all filter materials is given in table 4.2.

TABLE 4.1

ANALYSIS OF VARIANCE OF SOIL DISCHARGED

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F
Filter materials	6	367.20	61.21	102.0[a]
Perforation types	1	0.62	0.62	1.03[b]
Filters x Perforations	6	5.81	0.968	1.61[b]
Error	15	9.14	0.60	

a - significant at the one per cent level

b - not significant at the five per cent level

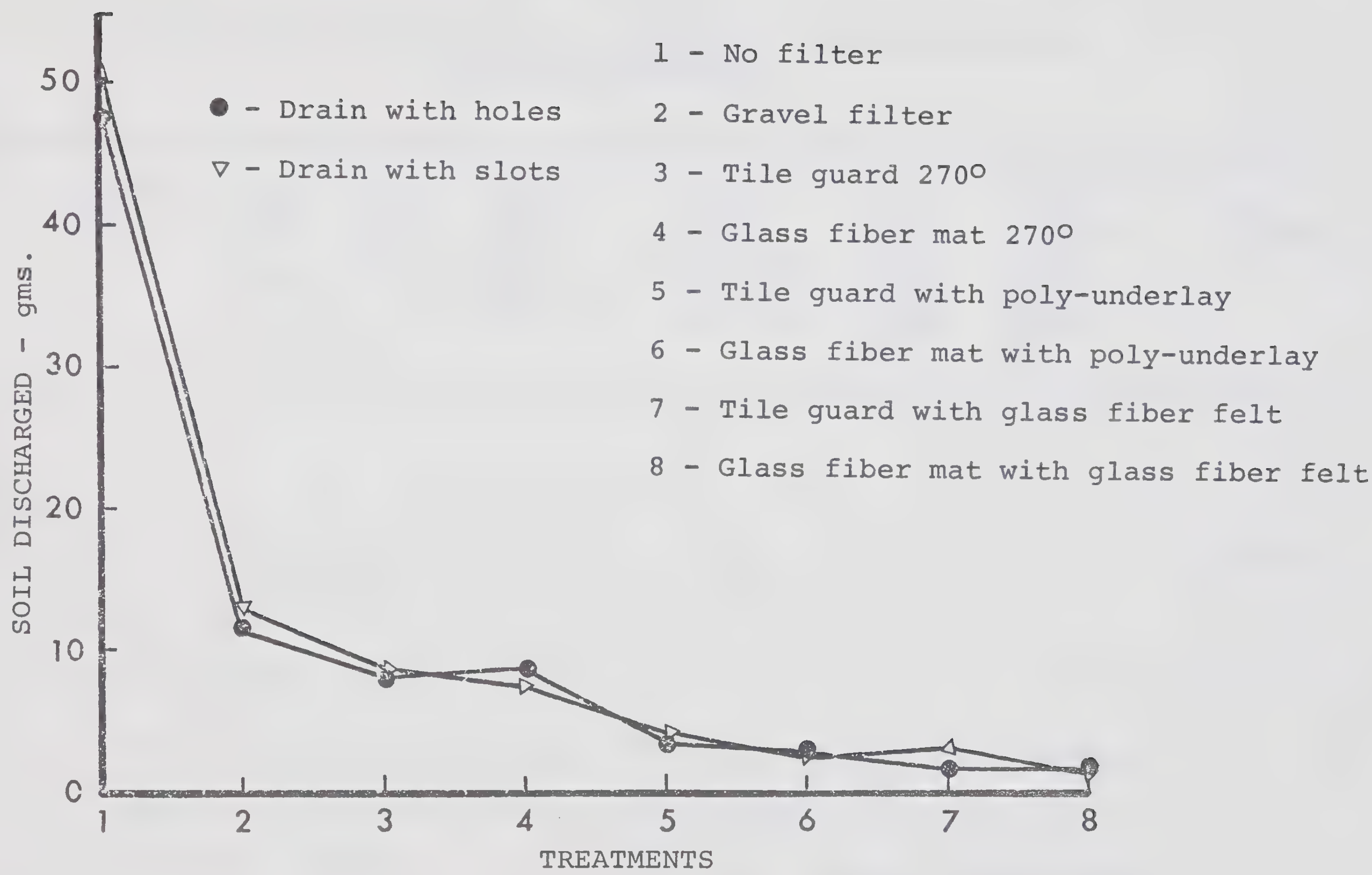


Figure 4.3. Response curve for interaction of filters and perforations for soil movement

TABLE 4.2

COMPARISON OF THE OVER-ALL EFFECT OF FILTER MATERIALS ON SOIL DISCHARGED

	Gravel filter	Glass fiber mat 270°	Tile guard 270°	Tile guard with poly-underlay	Glass fiber mat with poly-underlay	Tile guard with glass fiber felt	Glass fiber mat with glass fiber felt	No filter
Mean soil discharged (grams)	12.25	8.22	8.42	3.85	2.99	2.58	1.88	49.00

Any two means in this table and those following not underscored by the same line are significantly different. Any two means underscored by the same line are not significantly different.

Since the type of perforations in the drain had no significant effect on soil movement into the drain, the effect of perforation type was neglected while making this comparison. For the purpose of this investigation, a difference equal to or greater than that required at the five per cent level was considered sufficient difference for significance. This statement applies to this as well as all other statistical comparisons in this report. Considering the over-all results, table 4.2 shows glass fiber mat with glass fiber felt, tile guard with glass fiber felt and the glass fiber mat with poly-underlay provided the best protection against soil movement and ranked in descending order in the sequence listed above. These materials were not significantly different from each other. Tile guard with poly-underlay ranked fourth in providing protection against soil movement. While tile guard with poly-underlay was not significantly different from glass fiber mat with poly-underlay, it was significantly different from glass fiber mat with glass fiber felt and tile guard with glass fiber felt. Glass fiber mat 270^{o} and tile guard 270^{o} provided comparatively poor protection and ranked fifth and sixth respectively. However, these treatments provided significantly better protection than the gravel filter and the treatment without a filter and were not significantly different from each other. Gravel filter ranked seventh by providing significantly poor protection as compared to

other treatments except for the treatment without a filter, which was obviously significantly poorer than all other treatments.

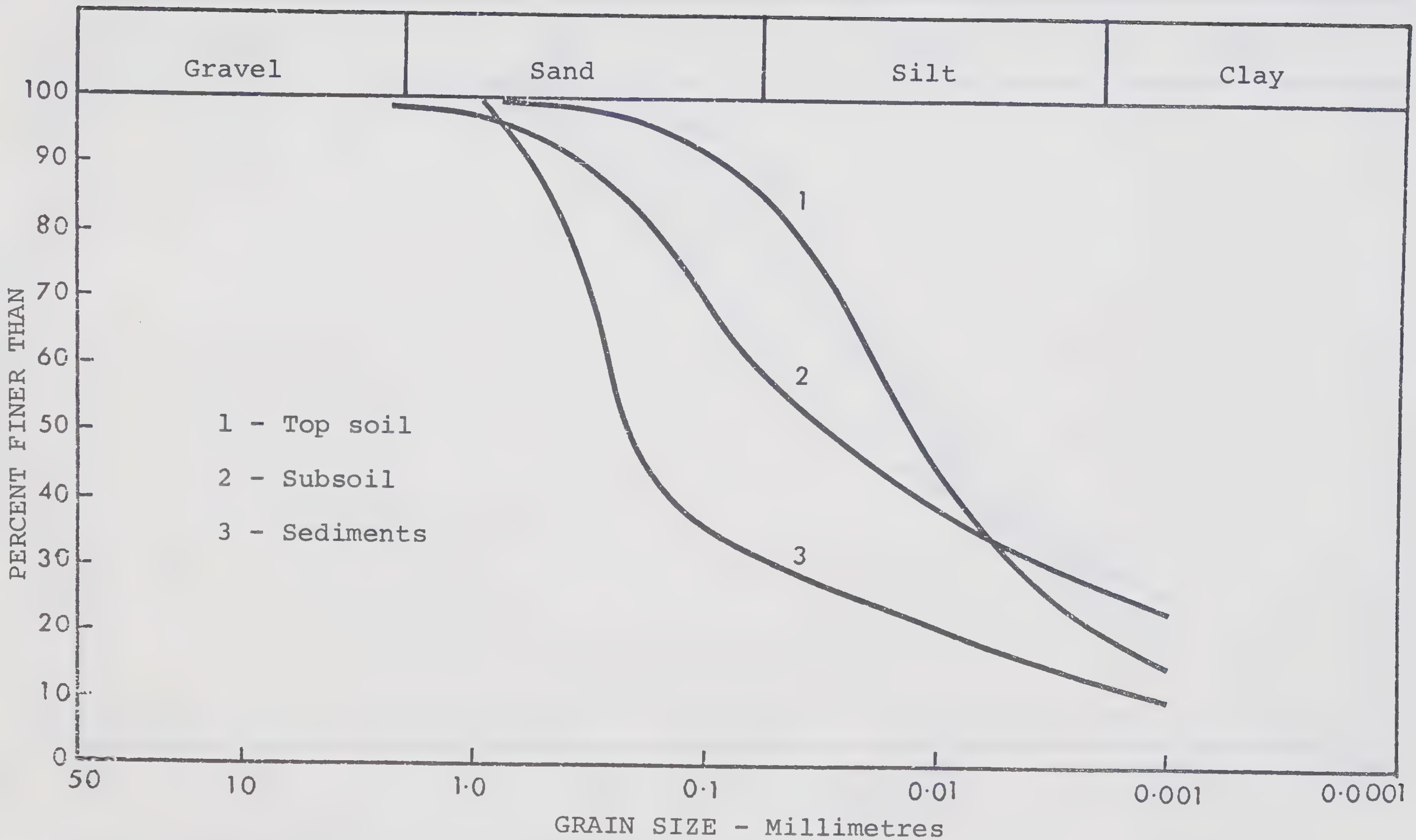
Since glass fiber mat and tile guard were major filter materials used to cover the top three-fourths of the drain, these materials were compared for sediment discharge for different placement conditions and combinations of these with other materials. The unpaired "t" test(43) was applied for making the comparison. The results of the comparison presented in table 4.3 show that the glass fiber mat for all placement conditions and combinations provided better protection against sedimentation as compared with tile guard under similar placement conditions or combinations. There was no significant difference between these materials for the 270° wrap and with glass fiber felt below-the-drain treatments. However, both materials provided significantly different protection against sedimentation while combined with poly-underlay.

A mechanical analysis was made on the soil moved into the drain under each treatment. The results of the analysis are shown in figure 4.4. Significant changes in the composition of the original soil and the soil moved into the drain occurred under all treatments. The percentage increase or decrease of sand and silt and clay fractions in the sediments as compared with the original base soil is shown in table 4.4. These percentage changes were

TABLE 4.3

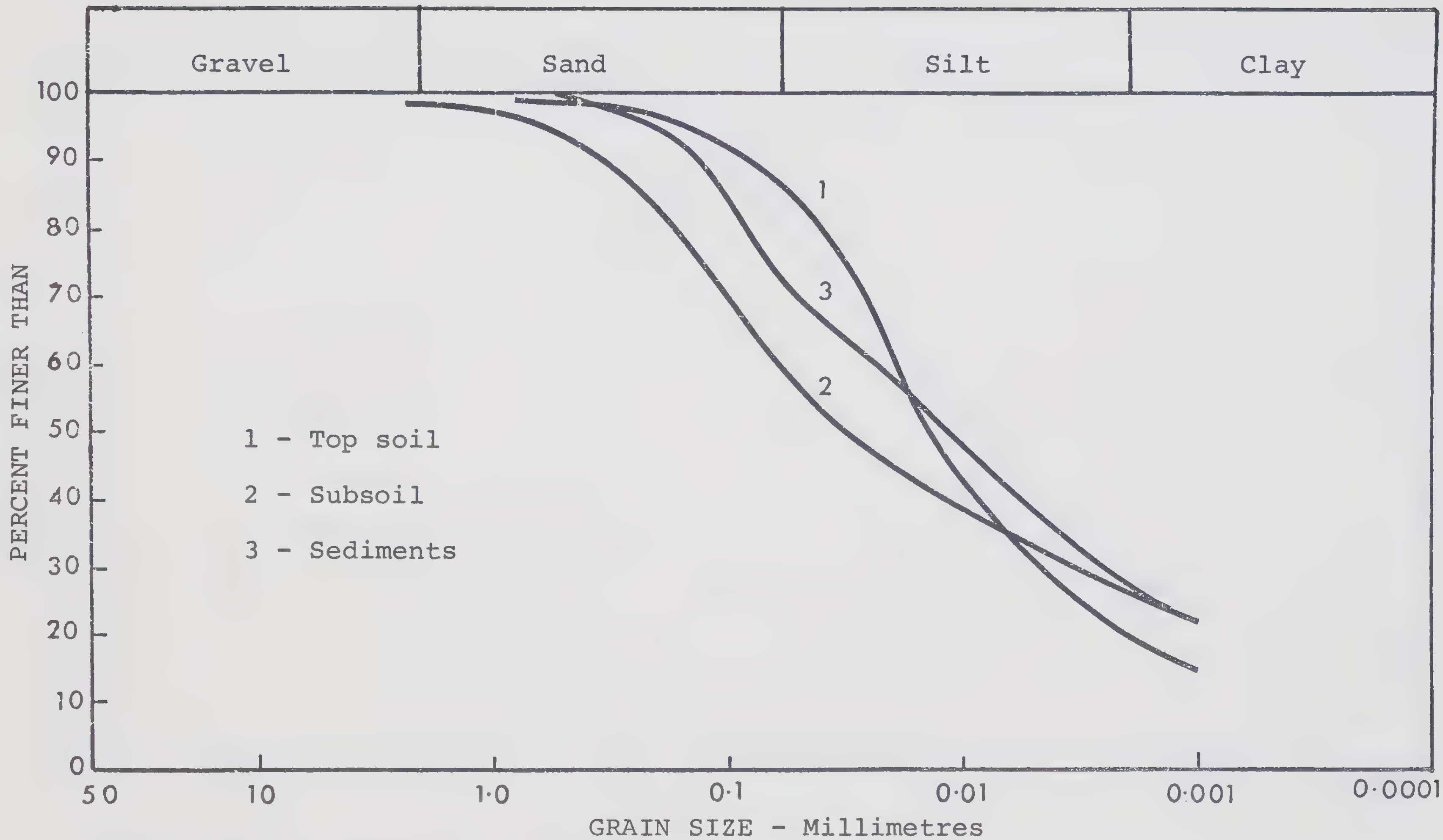
SOIL DISCHARGE FOR GLASS FIBER MAT AND TILE GUARD
FOR
DIFFERENT PLACEMENT CONDITIONS AND COMBINATIONS
(Soil discharge in grams)

Placement Condition/Combination	Glass Fiber Mat	Tile Guard
Top three-fourths of drain	8.22	8.42
With glass fiber felt	1.88	2.58
With poly-underlay	2.99	3.85



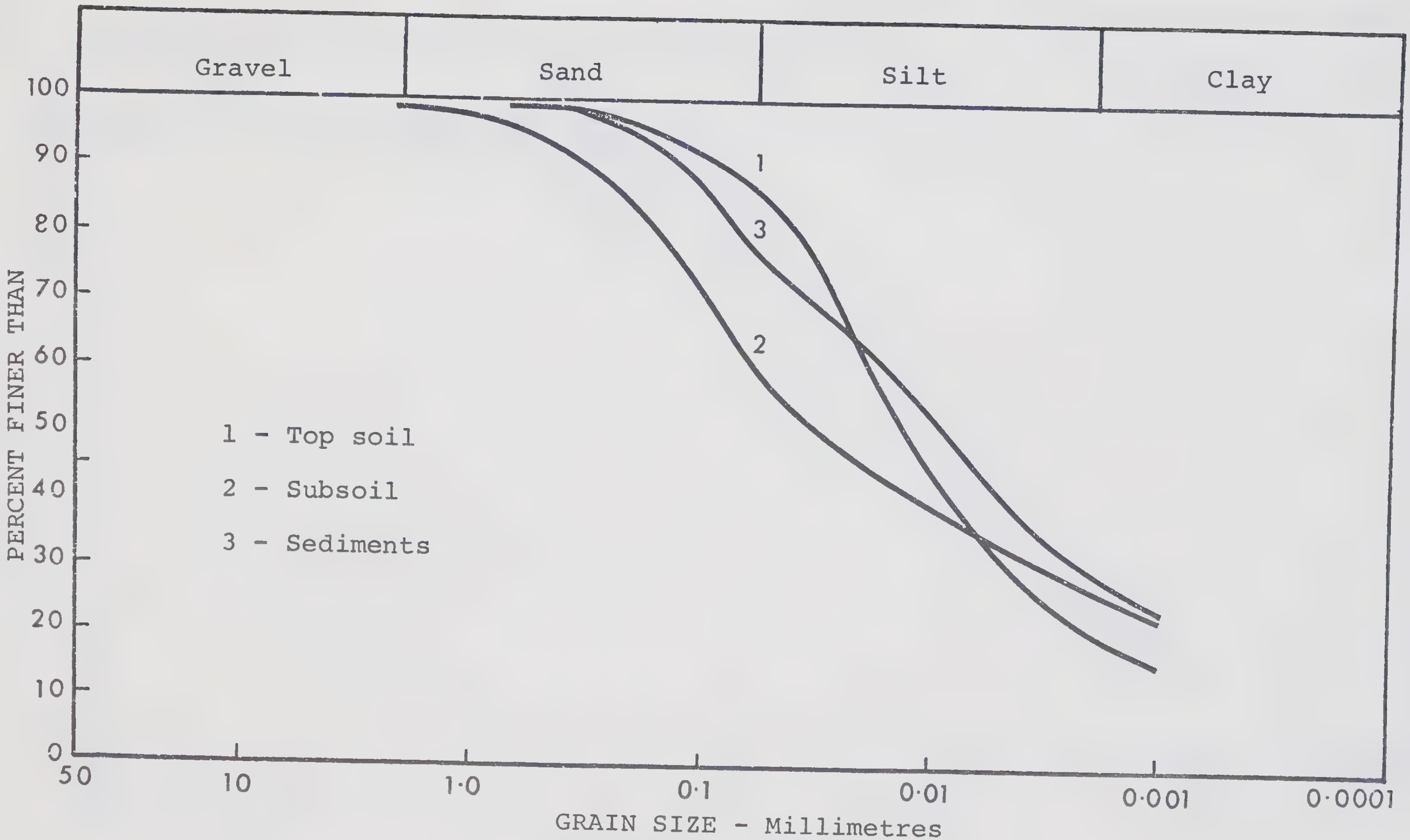
GRAVEL FILTER

Figure 4.4. Grain size distribution of base soil and sediments entering the drain tube.

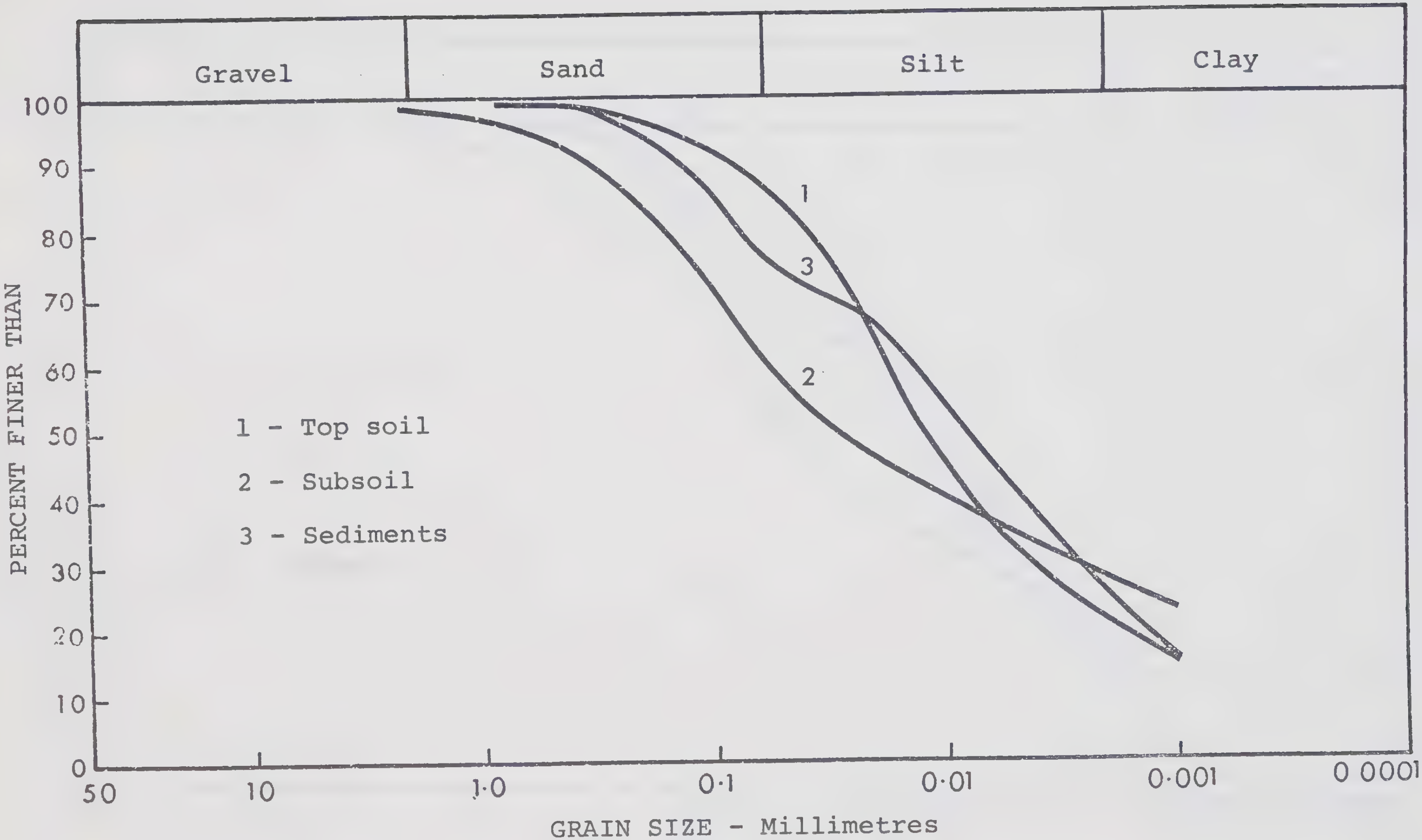


GLASS FIBER MAT WITH GLASS FIBER FELT

Figure 4.4 (continued)

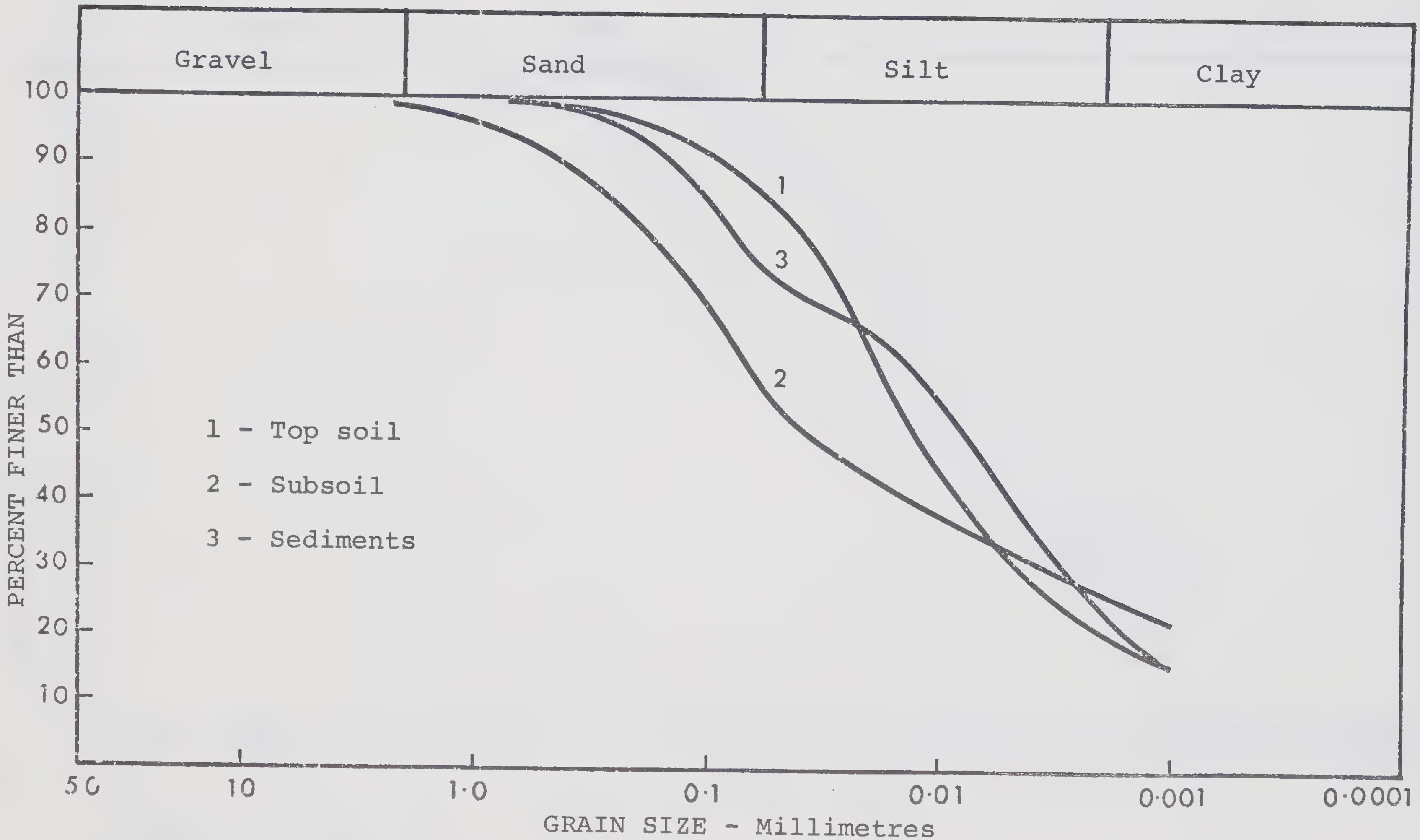


GLASS FIBER MAT WITH POLY-UNDERLAY
Figure 4.4 (continued)

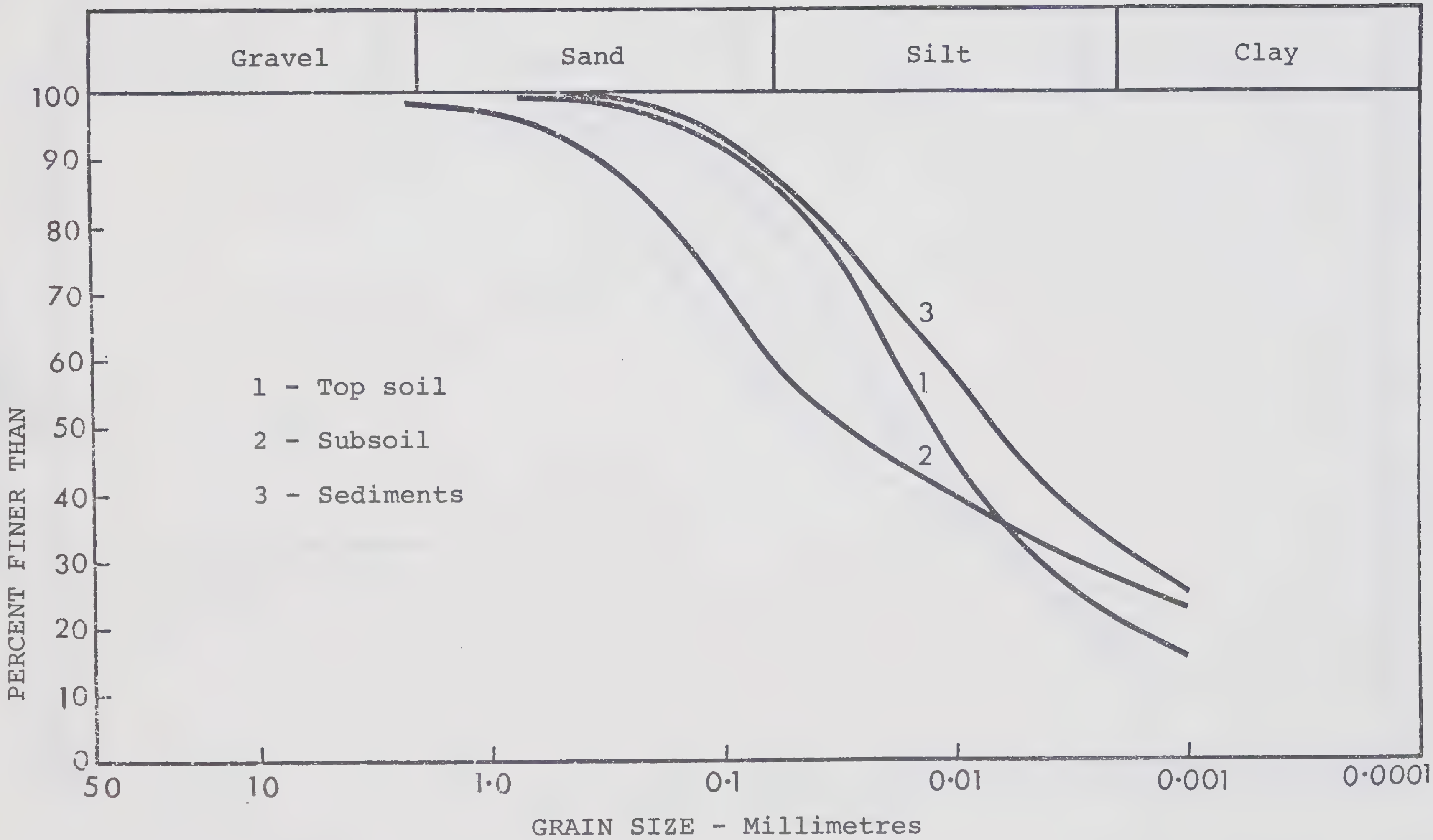


TILE GUARD WITH GLASS FIBER FELT

Figure 4.4 (continued)

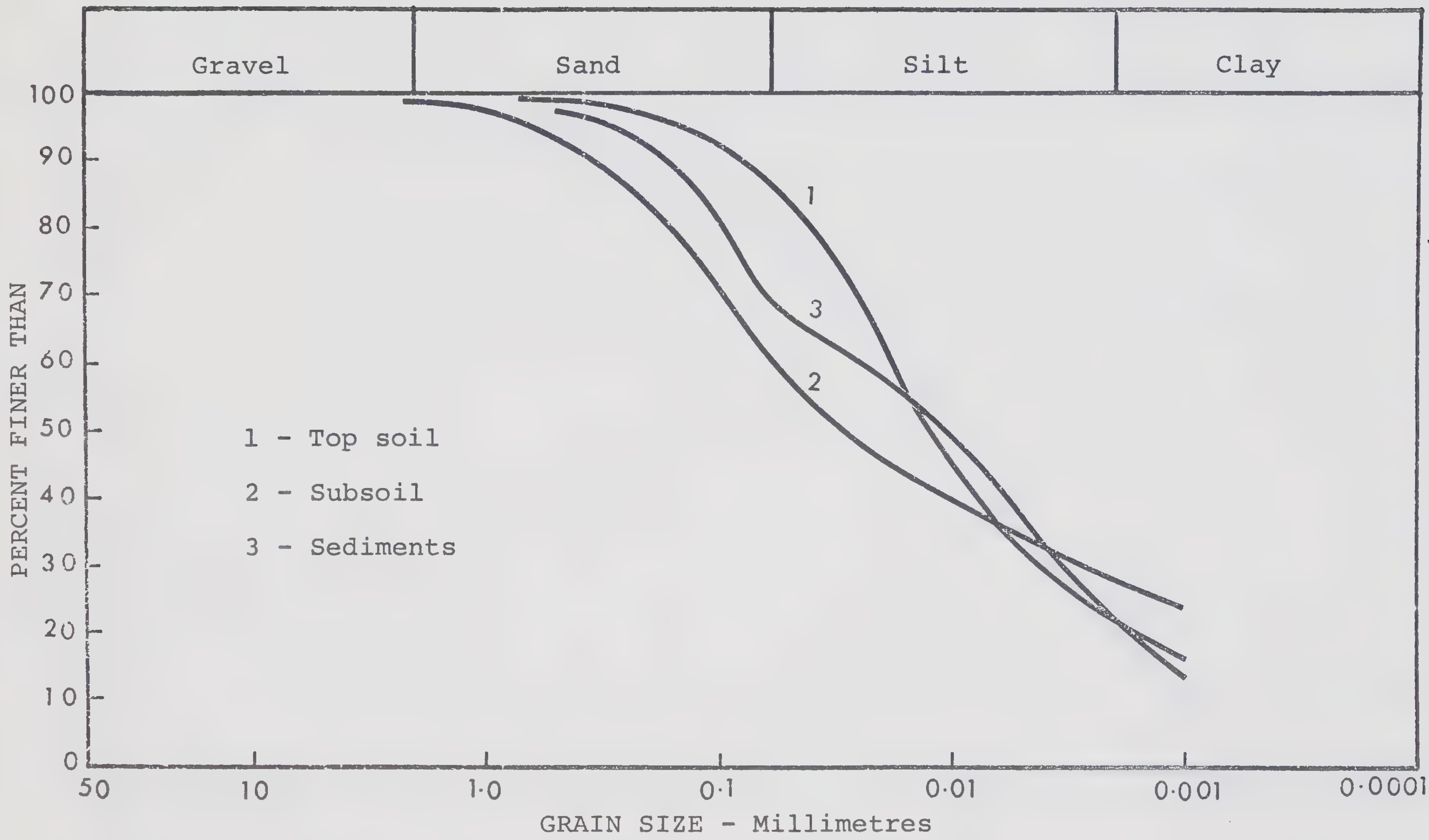


TILE GUARD WITH POLY-UNDERLAY
Figure 4.4 (continued)



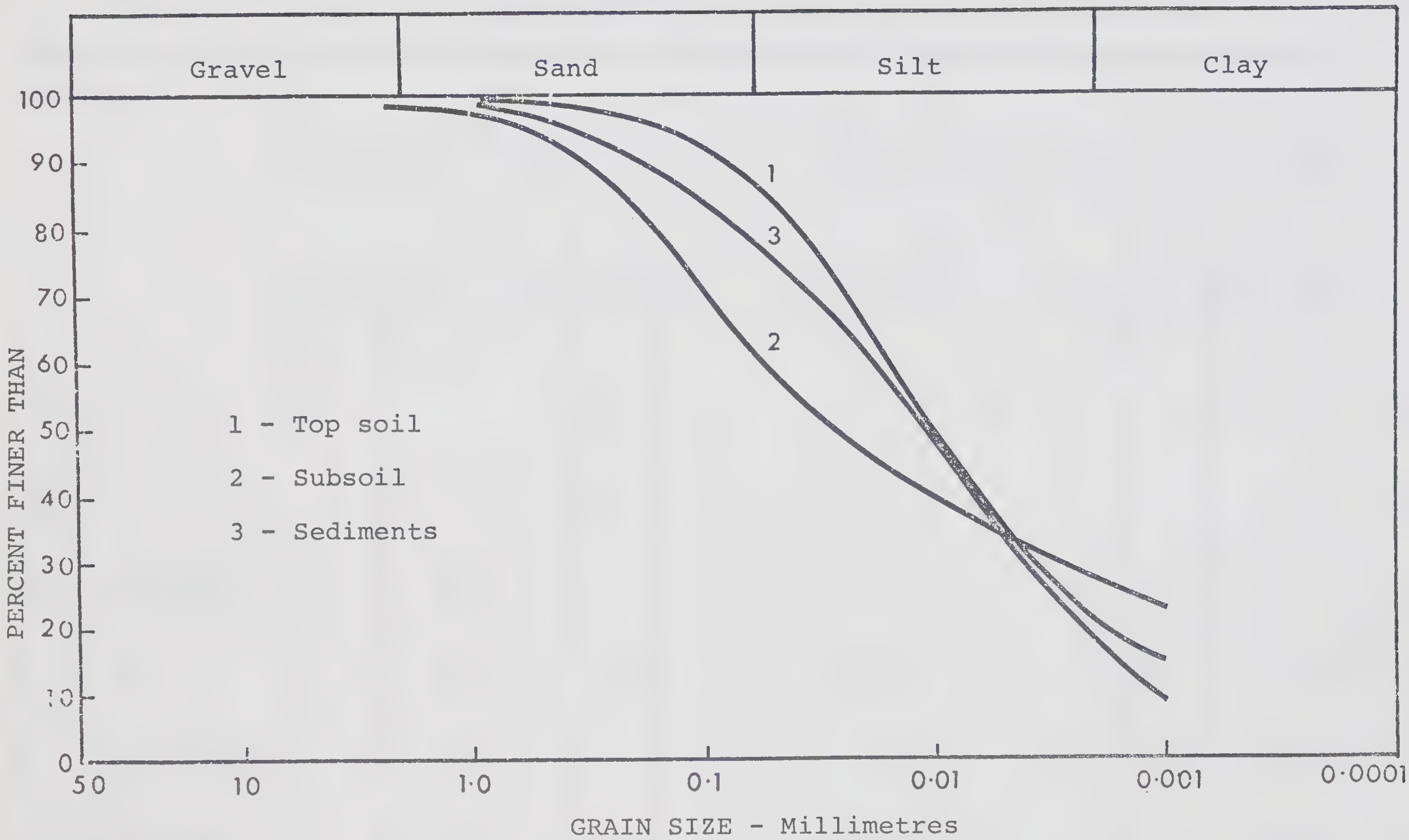
GLASS FIBER MAT 270°

Figure 4.4 (continued)



TILE GUARD 270°

Figure 4.4 (continued)



NO FILTER

Figure 4.4 (continued)

TABLE 4.4
PERCENTAGE CHANGE IN COMPOSITION OF SEDIMENTS FROM THAT OF BASE SOIL

Treatment	Change in Composition							
	Percentage increase in sand and silt and clay fractions				Percentage decrease in sand and silt and clay fractions			
	Subsoil		Top soil		Subsoil		Top soil	
	Sand	Silt & clay	Sand	Silt & clay	Sand	Silt & Clay	Sand	Silt & Clay
No filter		25.0	66.6		44.5			9.1
Gravel filter	86.0		459.0			48.4		62.5
Glass fiber mat with glass fiber felt		17.2	108.0		30.6			16.5
Glass fiber mat with poly-underlay		25.0	66.6		44.5			9.1
Glass fiber mat 270°		37.5	16.7		66.6			2.3
Tile guard with glass fiber felt		21.9	83.4		38.8			12.8
Tile guard with poly-underlay		20.4	91.5		36.1			12.5
Tile guard 270°		14.1	125.0		25.0			17.0

calculated on the basis of the composition of both fractions in the base soil. For all treatments except the gravel filter, the sediments discharged in the drain had less sand fraction and greater silt and clay fraction than the subsoil. However, compared to the top soil, the sediments had a lesser amount of silt and clay and a higher fraction of sand. This shows that the sediment composition falls between the composition of the top soil and subsoil, the sediments being coarser than top soil, but finer than subsoil. This suggests that some subsoil as well as top soil was carried into the drain.

For the gravel filter, the sediments had a higher fraction of sand and a lower fraction of silt and clay in comparison with both subsoil and the top soil. The greater fraction of sand may be due to the discharge of sand from the filter along with sediments.

In the glass fiber mat with glass fiber felt, glass fiber mat with poly-underlay, tile guard with glass fiber felt and tile guard with poly-underlay treatments, the increase in fine particles is explained by the fact that the perforations in the drain tube were covered completely by an effective filter material. The coarser particles that did enter the drain probably passed through the junction of the upper and lower layers of the materials applied above and below the drain. The sediment grain size distribution curves for glass fiber mat with glass fiber felt and glass fiber mat with poly-underlay were almost identical. Similarly, the grain size distribu-

tion curves for tile guard with glass fiber felt and tile guard with poly-underlay were identical to each other. This shows that the major portion of the sediments entered through the top three-fourths of the drain covered by glass fiber mat or tile guard. For these four treatments, as the drain tube was completely wrapped with filter material, the sediment grain size distribution curves should represent the pore size distribution of the filter materials applied. This may not necessarily be true, because some particles might have entered the drain through the junction between the material at the top and below the drain. However, grain size distribution curves give an indication of the sizes of particles that would be protected by the different treatments applied. Base soil fractions to the right of the sediments grain size distribution curves will not be protected, whereas the base soil fractions to the left of the curves will be filtered out of the water entering the drain.

Under tile guard 270° treatment, the relatively large increase in the sand fraction as compared to top soil, and the relatively small decrease in sand fraction compared to the base soil, could be explained by the fact that the bottom one-fourth of the drain was not covered with any material. However, for glass fiber mat 270° treatment, the percentage sand fraction is even less than the treatments in which the drain was completely wrapped with filter material. There is no apparent explanation for

this, except that the results may not be giving the true representation.

With no filter treatment, the sediments had a more uniform grain size distribution than under any other treatment. The sediment grain size distribution curve falls within the size ranges of subsoil and the top soil. This indicates that sediments washed from the soil profile were discharged into the drain without any restriction.

Even if the sand and silt and clay fractions for no-filter and glass fiber mat with poly-underlay treatments are the same, the latter will provide significantly greater protection against sedimentation due to its well graded size distribution curve.

As mentioned previously, the base soil used for this investigation was a medium textured loam, rather than light textured sandy soil used by most investigators. The mechanical analysis and Atterberg limits test results indicated that the problem of drain siltation would be encountered if the underground drains were laid in this area. However, there were no field data available to support the argument. The results of this investigation show that a completely unprotected drain tube allowed up to about thirty times more sediments to be discharged into the drain tube than where the tube was protected with filter material. However, these results are only comparative ones. The amount of sediments discharged into the unprotected drain during the five hour test run was

not as high as reported for light textured sandy soils (14, 34). This indicates that siltation hazard in the base soil used in this investigation would not be as severe as in light textured sandy soils. Thus, for the type of base soil used, the drain tube was not expected to be completely plugged with sediments in a matter of hours as reported for light textured sandy soils.

The results of this investigation did not give any information on whether the sediment discharge into the drain tube would continue or the base soil around the drain would stabilize over a long period. The soil around the drain after each test run was muddy, rather than porous. This was in contrast to observations made by Taylor and Goins(37) in a stable soil not causing any siltation problem. This indicates that the sediment flow will continue over a long period of time. If this happens, then there are opportunities of drains being plugged with sediments even at comparatively lower rates of sediment discharge.

Protection against soil movement by the filter materials tested agrees with the results obtained by other investigators. Overholt(29) found that unprotected drain tile allowed an average of 3.49 times more silt to be discharged than when the tiles were protected by wrapping the top three-fourths of the drain with glass fiber material. In the tests reported here, it can be shown that completely unprotected drain tube allowed approximately six times

more sediments to be discharged into the drain tube than where the tube was protected with either glass fiber mat or the tile guard over the top three-fourths of the drain. However, in this investigation, the drain tube used was plastic with perforations while Overholt used a tile drain with gaps. Sisson(34) reported that glass fiber mat over the top three-fourths of the drain and plastic sheet below the drain provided better protection against sedimentation than covering only the top three-fourths of the drain. In a laboratory investigation, Hore and Tiwari(14) observed that tile guard above and below, and tile guard above and Duramat below the drain provided better protection against sediment movement than tile guard above the drain only. Although these observations were made on a tile drain with gaps, rather than plastic tubing with perforations, they do agree with the results reported here.

The fact that the gravel filter allowed a significantly greater amount of soil movement than glass fiber mat and tile guard under various placement conditions or combinations, may indicate that some of the criteria being used for design of gravel filter needs further investigation.

Both glass fiber mat and tile guard provided almost comparable protection against the hazard of siltation. The pore size distribution for both materials shows the materials' capability to filter out the base soil around

the drain. However, a major problem with either of the materials could be its low tensile strength and thus may tear when used with the plow-in method.

4.3 Water Discharged

The rate of water discharged under ponded water flow conditions for different filter materials is shown in figure 4.5. The water flow rate was fairly constant during partially saturated flow conditions. As shown in figure 4.5, the flow rate for all filter materials increased during the first 10 to 15 minutes, then it started dropping and ultimately leveled off to a constant flow rate. As mentioned previously, the water flow rate measurements were started when the water first appeared in the drain. At this stage, the entire profile might not be contributing toward the flow through the drain and this might be the reason for the lower initial flow rates. After reaching a peak, the decrease in the rate of flow occurred either due to settlement of loose base soil around the drain, or by accumulation of fine soil particles in the filter material and base soil around the drain. Either of these two effects could have decreased the permeability of either the base soil or filter material or both, to cause a decrease in the flow rate.

The accumulative flow of water for the complete five hour test run for different filter materials is shown in figure 4.6. Under a ponded water saturated flow condition, the rate of flow for both glass fiber mat with poly-underlay

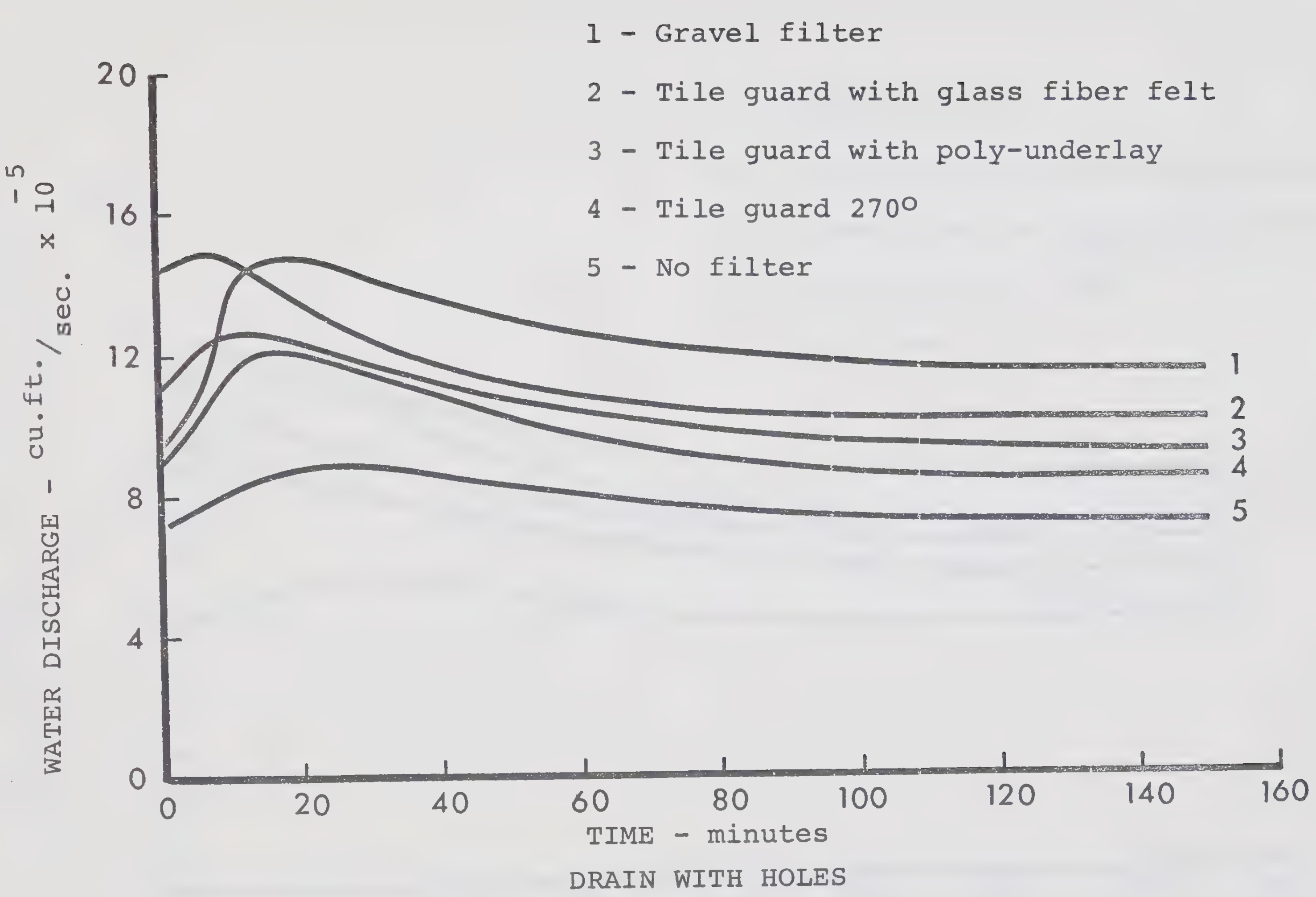


Figure 4.5. Water discharge for different treatments under ponded water flow condition.

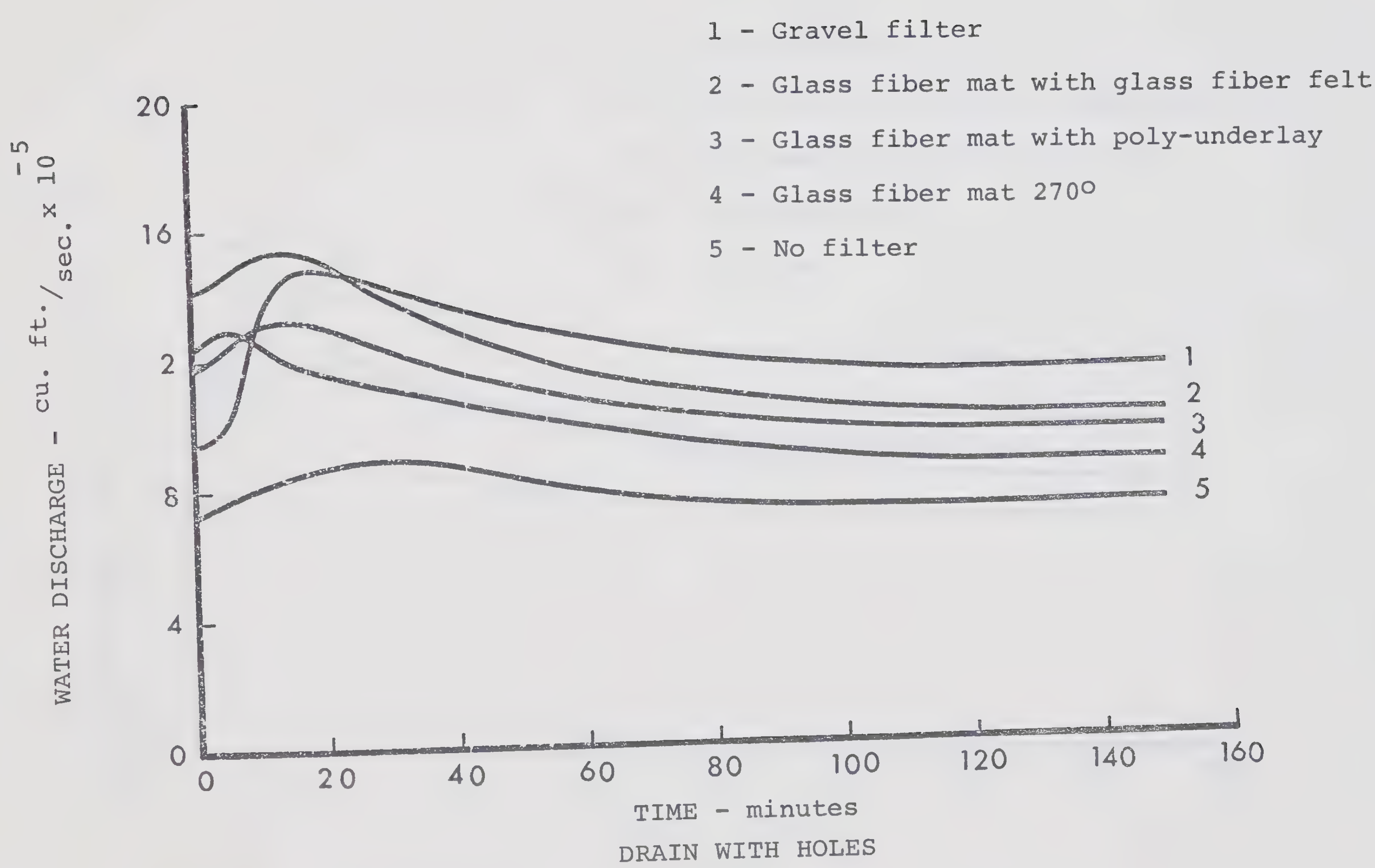
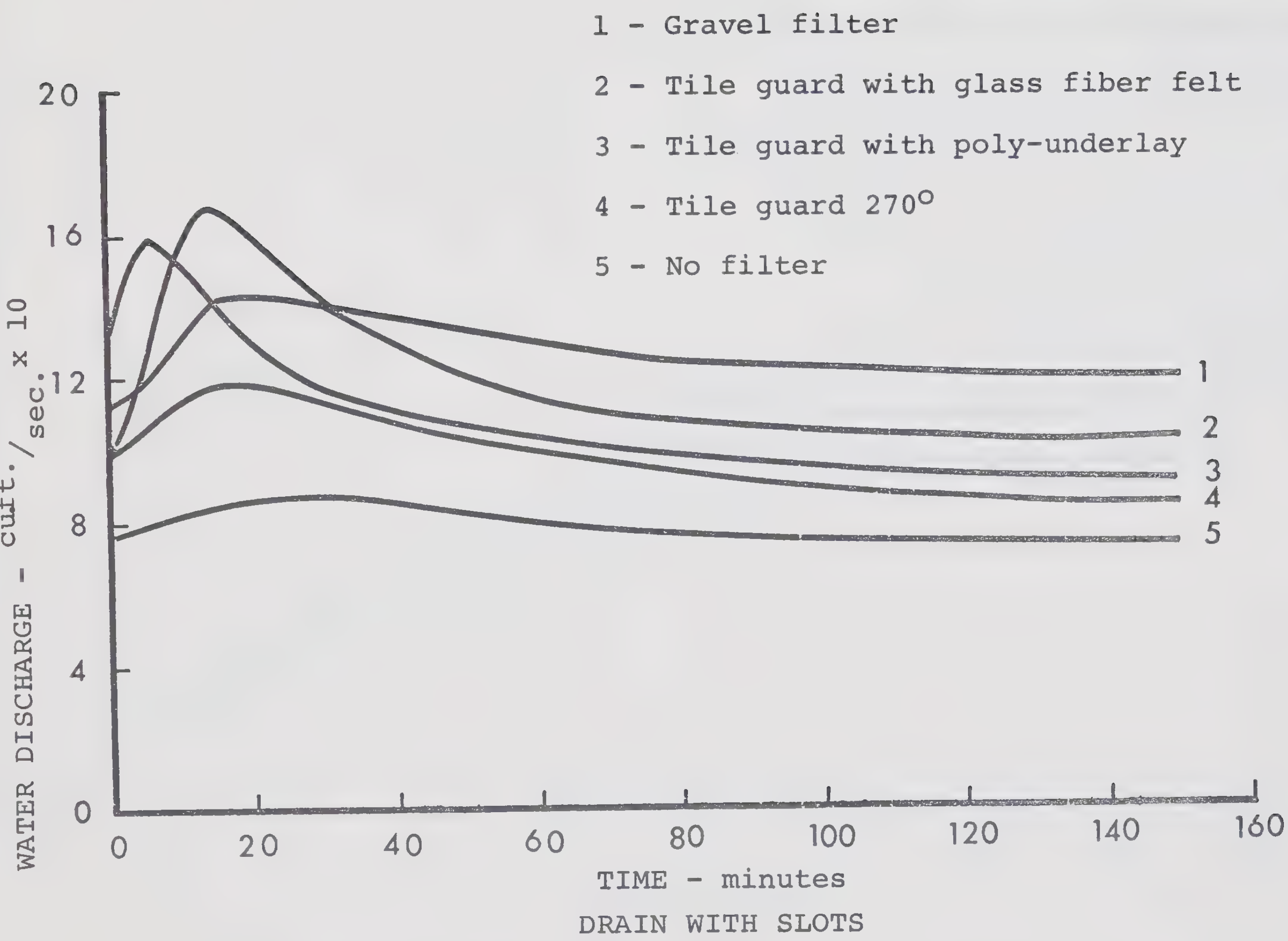


Figure 4.5. (Continued)



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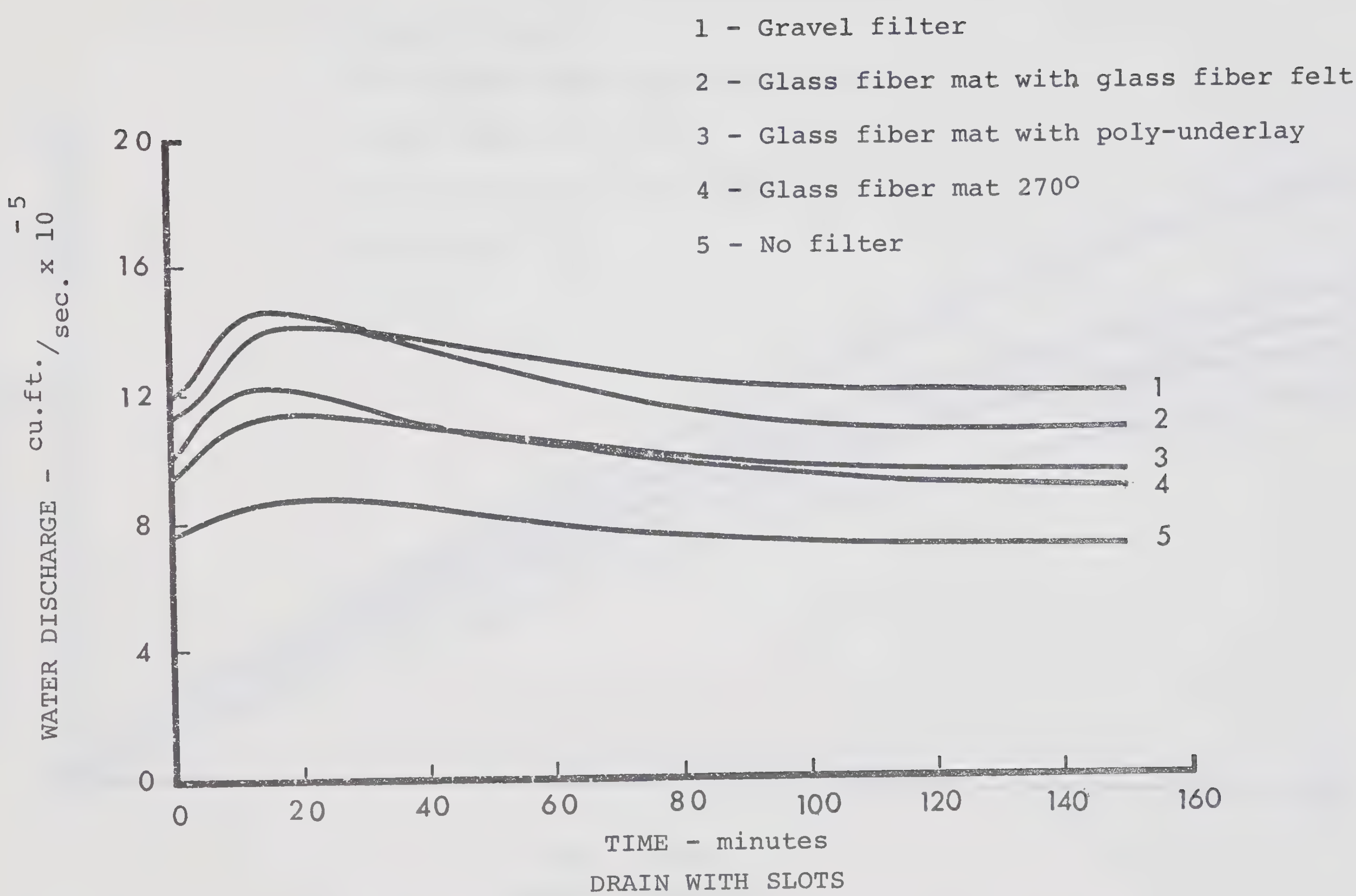

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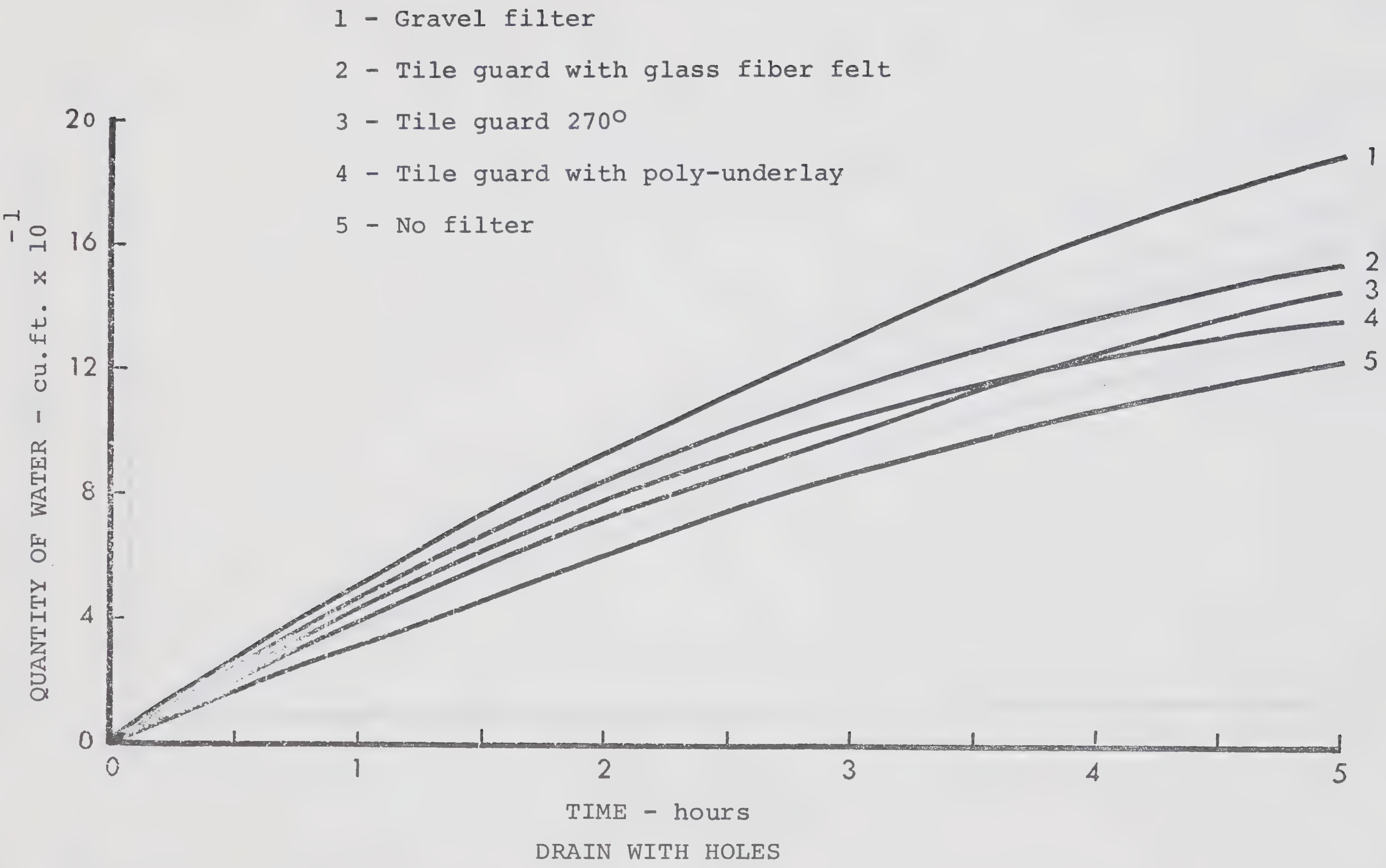
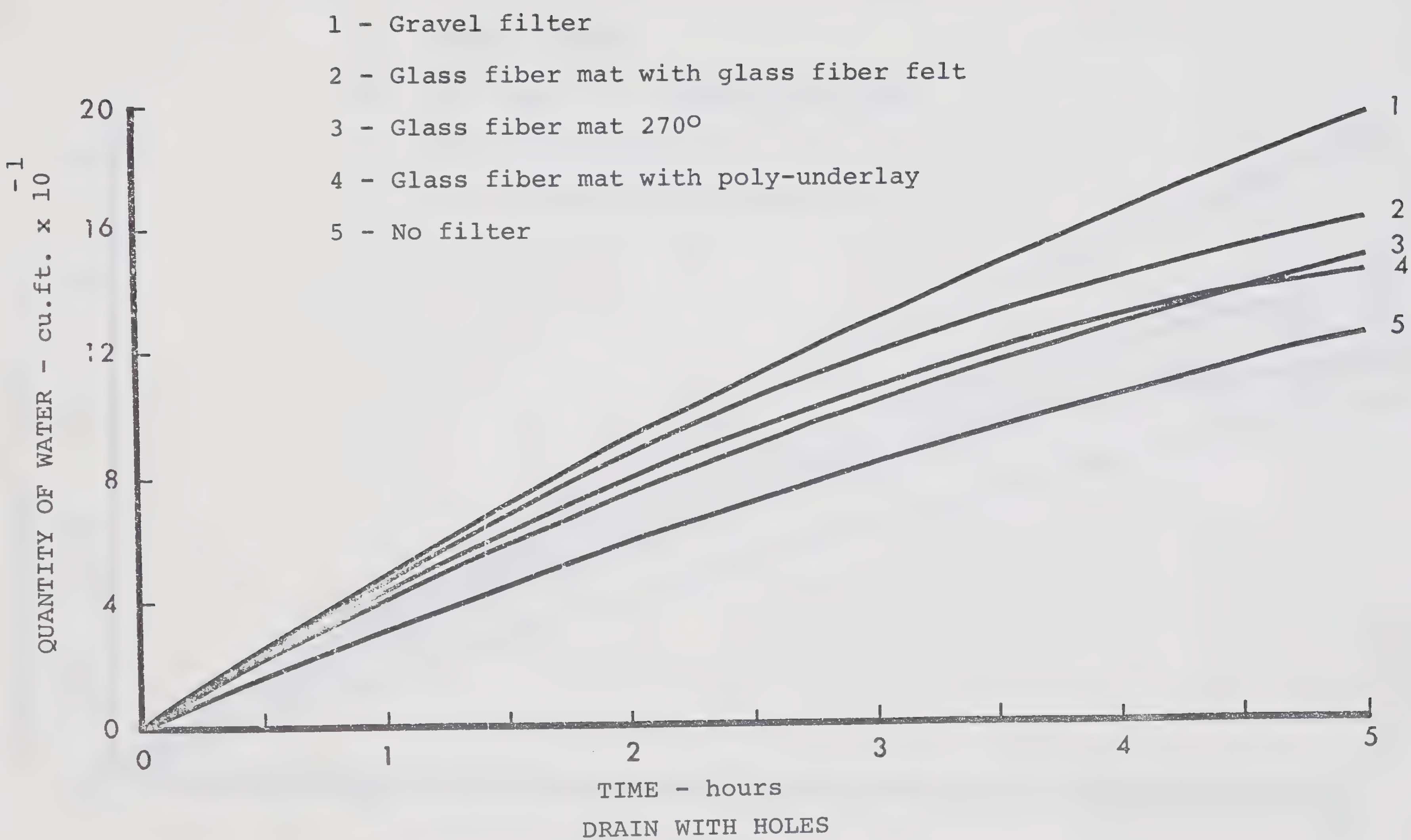


Figure 4.6. Accumulative flow curves for different treatments



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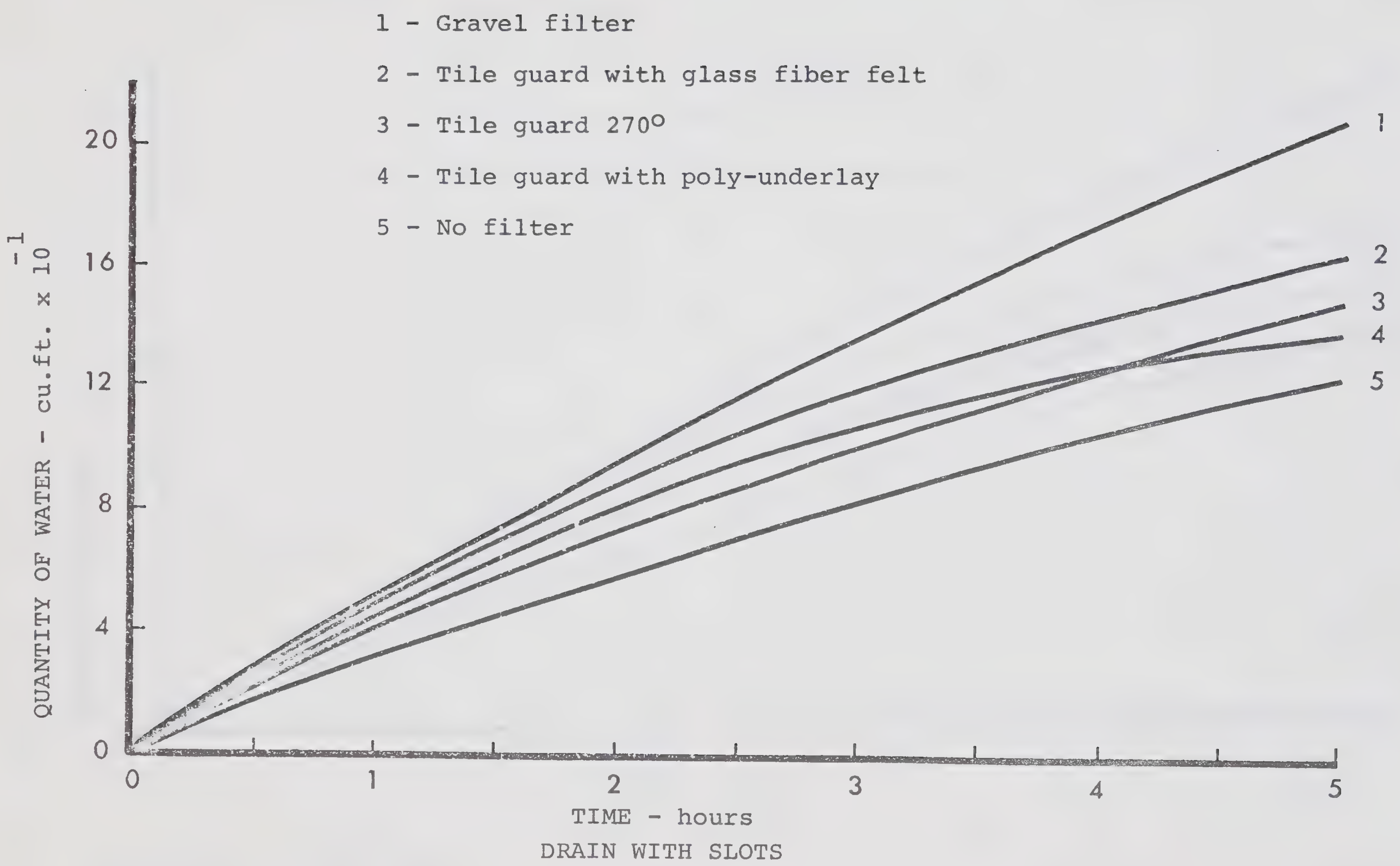

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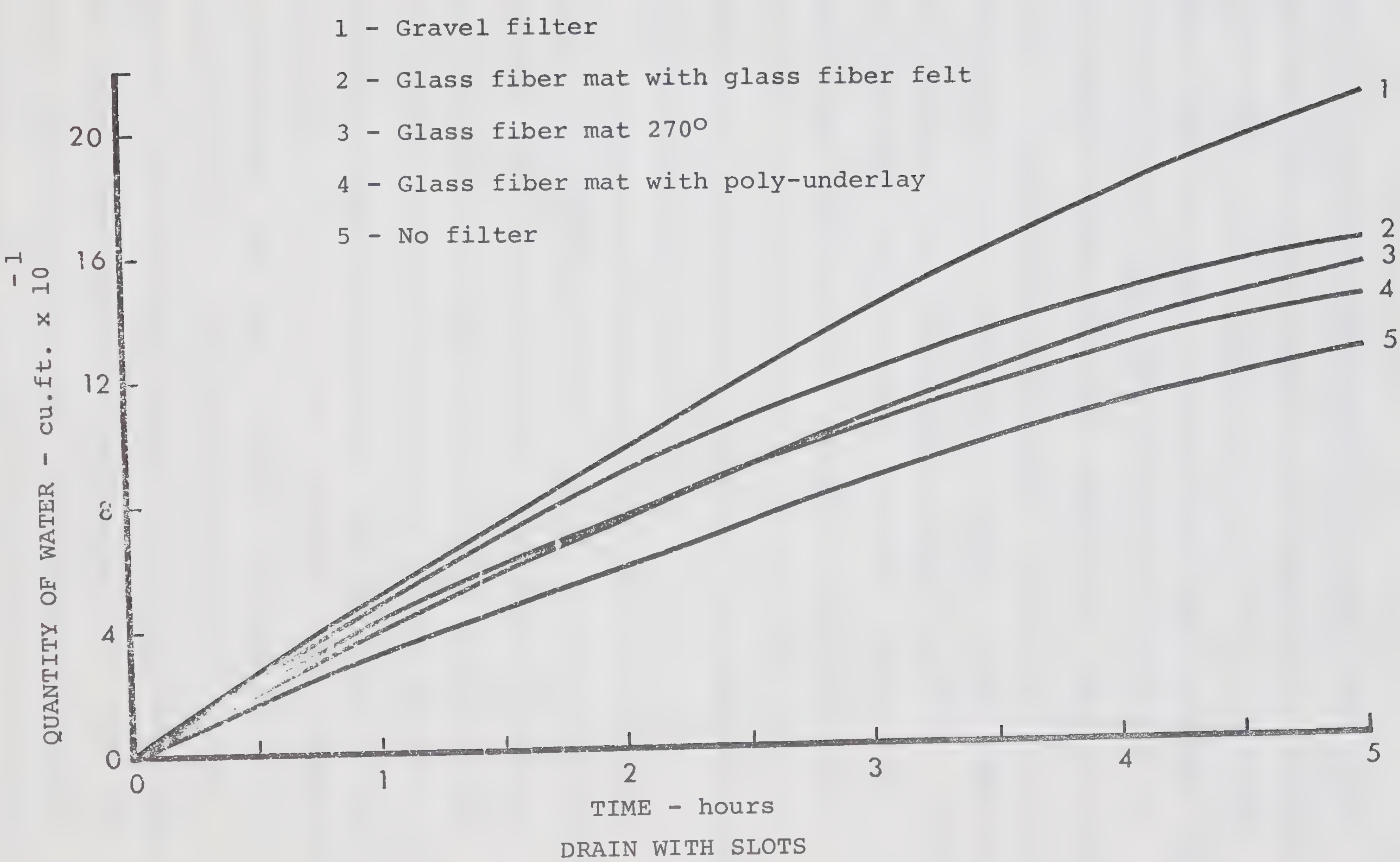

Figure 4.6. (Continued)

and tile guard with poly-underlay is greater than glass fiber mat 270° and tile guard 270° respectively. However, as indicated by the accumulative flow curves, the total flow of water for glass fiber mat 270° and tile guard 270° was greater than glass fiber mat with poly-underlay and tile guard with poly-underlay respectively. This indicates a higher flow rate under partially saturated flow conditions with glass fiber mat 270° and tile guard 270° as compared with treatments with poly-underlay below the drain. Since, under partially saturated flow conditions, most of the water enters the drain from the bottom or sides of the drain tube, the relatively lower rate of flow could be explained by the obstruction caused by the impermeable poly-underlay layer under the drain tube.

An analysis of variance was performed to test for significant differences in the results of water discharged. The total water discharged during five hours of test run was included in the analysis. A summary of the analysis of variance of water discharged is presented in table 4.5. The results show that the filter materials caused highly significant differences in the amount of water discharged at the one per cent level. However, the type of perforations did not have a significant effect on water discharged. The interaction between filters and perforations was a significant factor at the five per cent level, but not at the one per cent level. The response curve for interaction between perforation types and various treat-

TABLE 4.5

ANALYSIS OF VARIANCE OF WATER DISCHARGED

Source of variation	Degree of Freedom	Sum of Squares	Mean Square	F
Filter materials	7	5793.761	827.68	60.703[a]
Perforation types	1	14.399	14.399	1.54 [b]
Filters x Perforations	7	95.445	13.635	3.359[c]
Error	17	69.009	4,059	

a - significant at the one per cent level

b - not significant at the five per cent level

c - significant at the five per cent level but not at the one per cent level

ments is given in figure 4.7. The response curve does not indicate any regular trend in variation of water discharged due to the interaction. Therefore, no meaningful results can be derived even though the interaction is statistically significant.

An over-all comparison of the average amount of water discharged for all treatments is given in table 4.6. Since the perforation types did not significantly affect the water discharged, their effect was neglected while making the comparison. The results of the comparison show that the amount of water discharged with the gravel filter around the drain was significantly higher than the other treatments, while with the no-filter treatment the amount of water was significantly lower than all other treatments. The remaining six treatments showed a distinct division into two groups. Both tile guard and glass fiber mat showed significantly different amounts of water discharged between various placement conditions or combinations. However, they did not show significantly different results under similar placement conditions or combinations. Both materials in combination with glass fiber felt showed significantly higher results than 270° wrap over the top of the drain, which, in turn, gave significantly greater amounts of water flow in comparison with tile guard and glass fiber mat combined with poly-underlay.

Table 4.7 shows the comparison of water discharged for glass fiber mat and tile guard under different place-

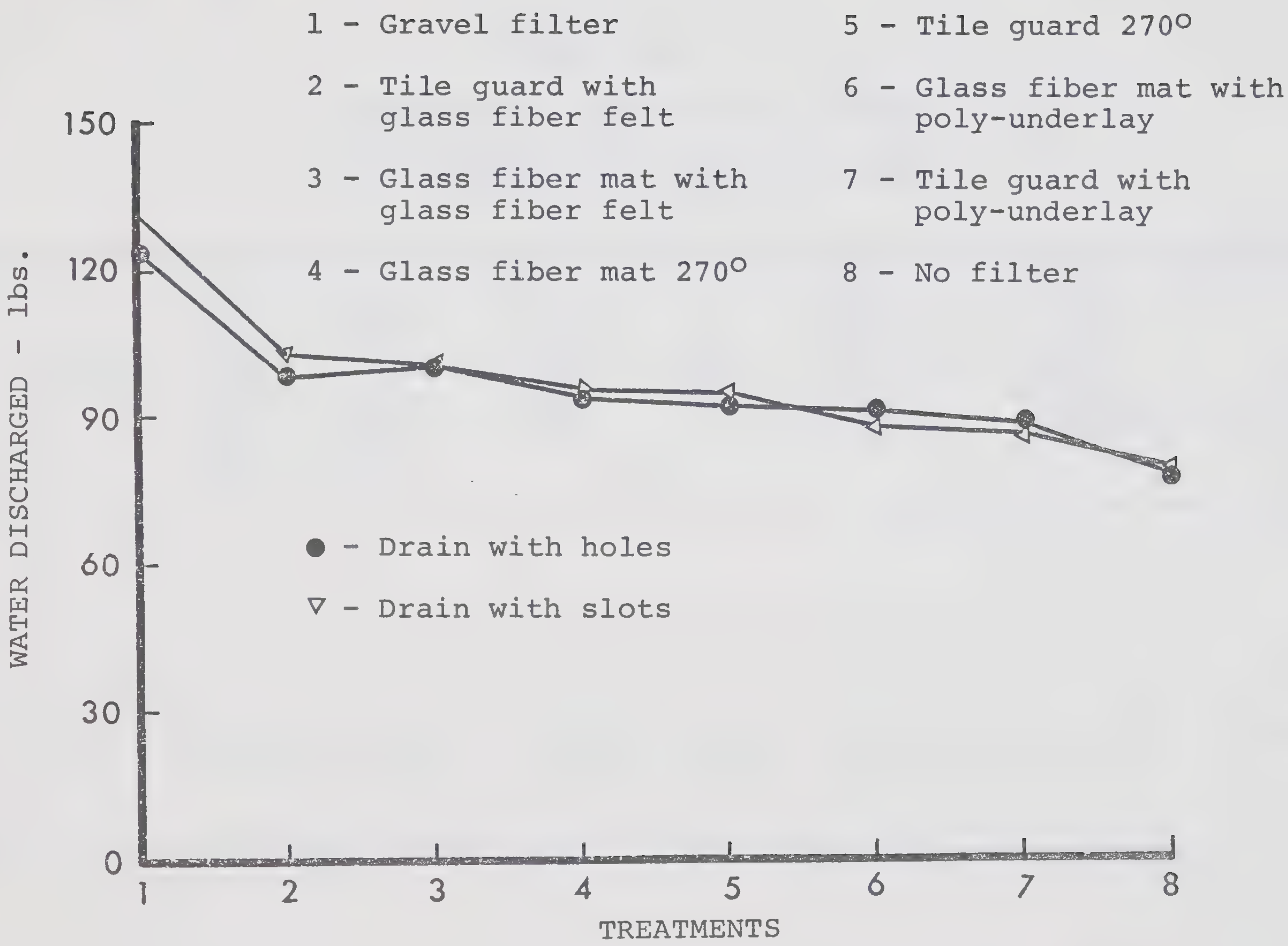

Figure 4.7. Response curve for interaction of filters and perforations for water discharged

TABLE 4.6

COMPARISON OF THE OVER-ALL EFFECT
OF
FILTER MATERIALS ON WATER DISCHARGED

	Gravel Filter	Tile guard with glass fiber felt	Glass fiber mat with glass fiber felt	Glass fiber mat 270°	Tile guard 270°	Glass fiber mat with poly-underlay	Tile guard with poly-underlay	No Filter
Mean water discharged (lbs.)	127.14	101.02	99.34	94.26	93.99	89.34	87.36	78.18

TABLE 4.7

WATER DISCHARGE FOR GLASS FIBER MAT AND TILE GUARD FOR DIFFERENT PLACEMENT CONDITIONS AND COMBINATIONS

(Water discharge, lbs.)

Placement Conditions/Combinations	Glass fiber mat	Tile guard
Top three-fourths of drain	94.26	93.99
With glass fiber felt	99.34	101.02
With poly-underlay	89.34	87.36

ment conditions or combinations. The unpaired "t" test (43) was applied for making the comparison. These results are also in accordance with the results of table 4.6. Therefore, the two filter materials, the glass fiber mat and the tile guard, did not affect the flow of water significantly.

The water discharged in these tests, in general, agrees with the results published by other investigators. Overholt(29) observed that the tile, where the top three-fourths of the circumference was covered with glass fiber sheet, gave 1.7 times greater rate of water flow as compared to tile without any filter. Hore and Tiwari(14) reported a significant difference in flow of water for glass fiber sheet above the drain and the drain without any filter. The results of this investigation show that glass fiber mat 270° and tile guard 270° treatments gave about 1.2 times greater flow of water than no filter treatment. In a laboratory comparison of several filter materials, Sisson(34) found a significantly higher flow rate for gravel filter as compared with glass fiber sheet over the top three-fourths of the drain and glass fiber sheet above, plastic below the drain. His observations are in agreement with the results of this investigation.

4.4 Potential Around the Drain

Twelve piezometric taps installed around the drain were connected to a manometer board to measure the pressure head around the drain. The potential was calculated by

the following formula taking the centre of the drain tube as a reference point.

$$H = P + G$$

where

H = potential or hydraulic head, ft. of water.

P = pressure head, ft. of water.

G = gravitational head, ft. of water.

Hydraulic head around the drain for both ponded water and partially saturated flow conditions is shown in figure 4.8. The measurements show that the potential around the drain for all filters was fairly constant. Under partially saturated flow conditions, only the no filter treatment had water standing above the drain.

The potential measurements made in the laboratory are not necessarily the same as found in the field and simply indicate the magnitude of the hydraulic gradient existing around the drain in the drain tank model.

4.5 Suction Head in the Soil Profile

Under partially saturated flow conditions, tension in the base soil above the drain tube was measured to determine the suction head in the soil profile and to compare the differences due to filter materials. For calculating the tension at various depths in the soil profile, the following formula(26) was used:

$$T = 12.6M - H - 13.6R$$

where

T = Tension, inches of water.

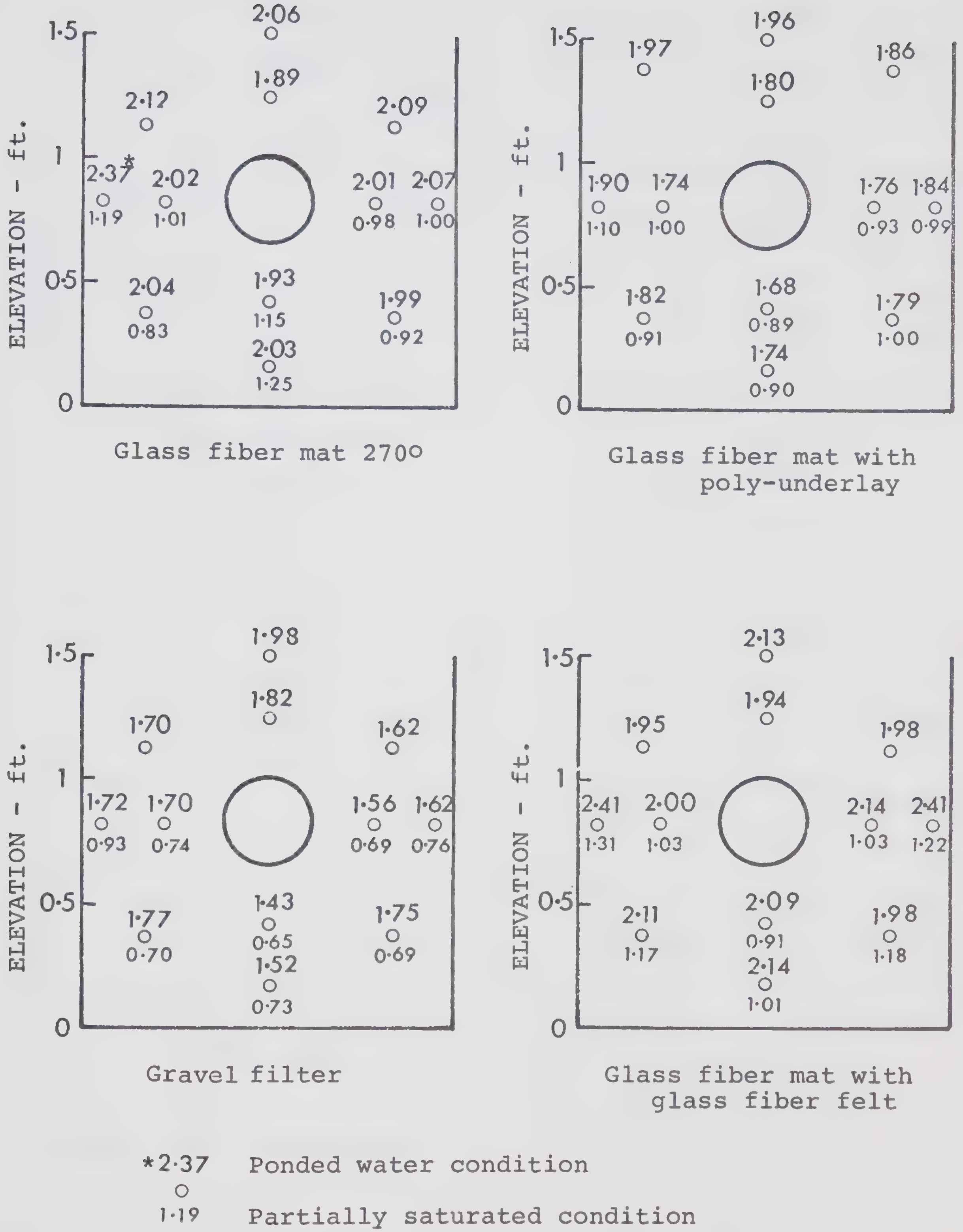

Figure 4.8. Potential distribution around the drain for each filter material

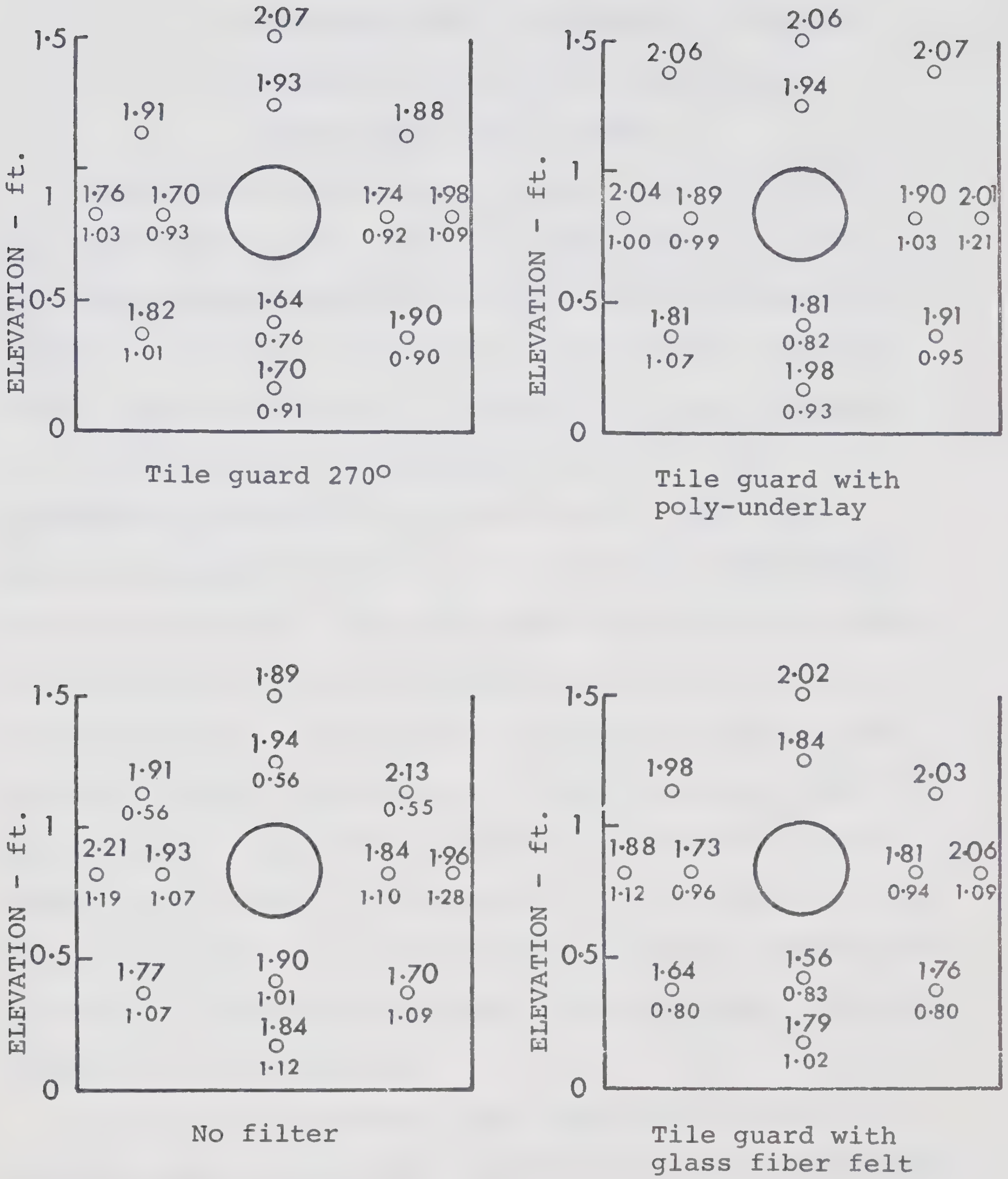

Figure 4.8. (Continued)

M = Meniscus level in manometer, inches.

R = Meniscus level in reservoir, inches.

H = Height of bottom of scale above tensiometer cell, inches.

Typical relationships of suction head distribution for the various filter materials are shown in figure 4.9. The head variation pattern for all filter materials was similar. In nearly every case, the pressure above the drain tube was negative in the base soil and decreased in magnitude from a maximum near the soil surface to atmospheric pressure at the drain tube. The slight positive pressure at the top of the drain tube with the no-filter treatment indicates that the water was standing on the top of the drain even during partially saturated flow conditions. This may be explained by the low permeability of the base material around the drain resulting in submerged conditions because of the constant rate of water supply under all treatments. The existence of the negative pressure throughout the soil profile confirms the presence of partially saturated flow conditions during the last half of the test run.

It must be emphasized that the situation described here is based on partially saturated flow with drain tube flowing nearly empty. The pressure distribution above the drain tube will change as the stage of flow in the drain tube increases. Regardless of the filter material, as soon as the drain tube flows full, a positive pressure

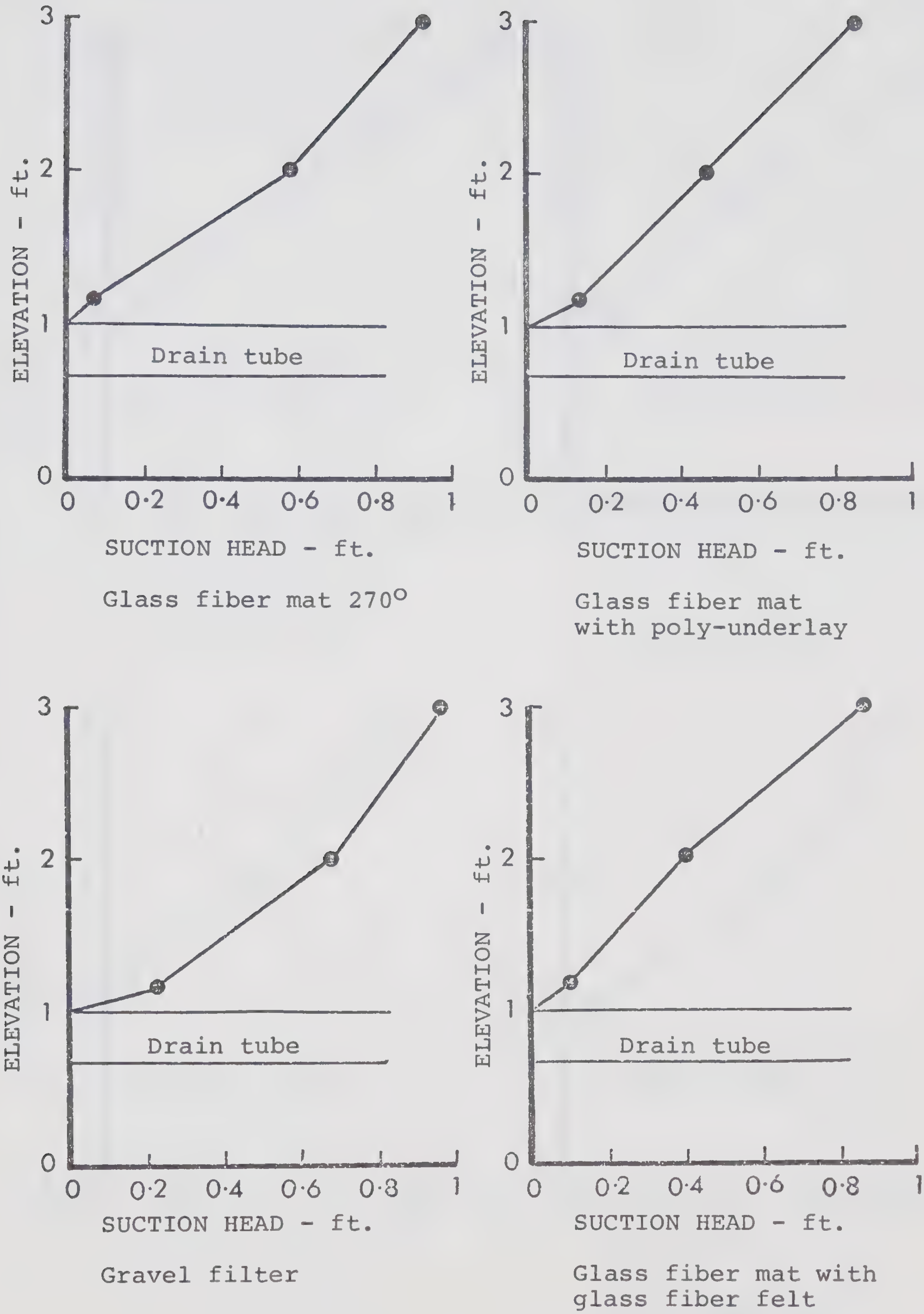

Figure 4.9. Suction head distribution in the soil profile above the drain tube for each filter material

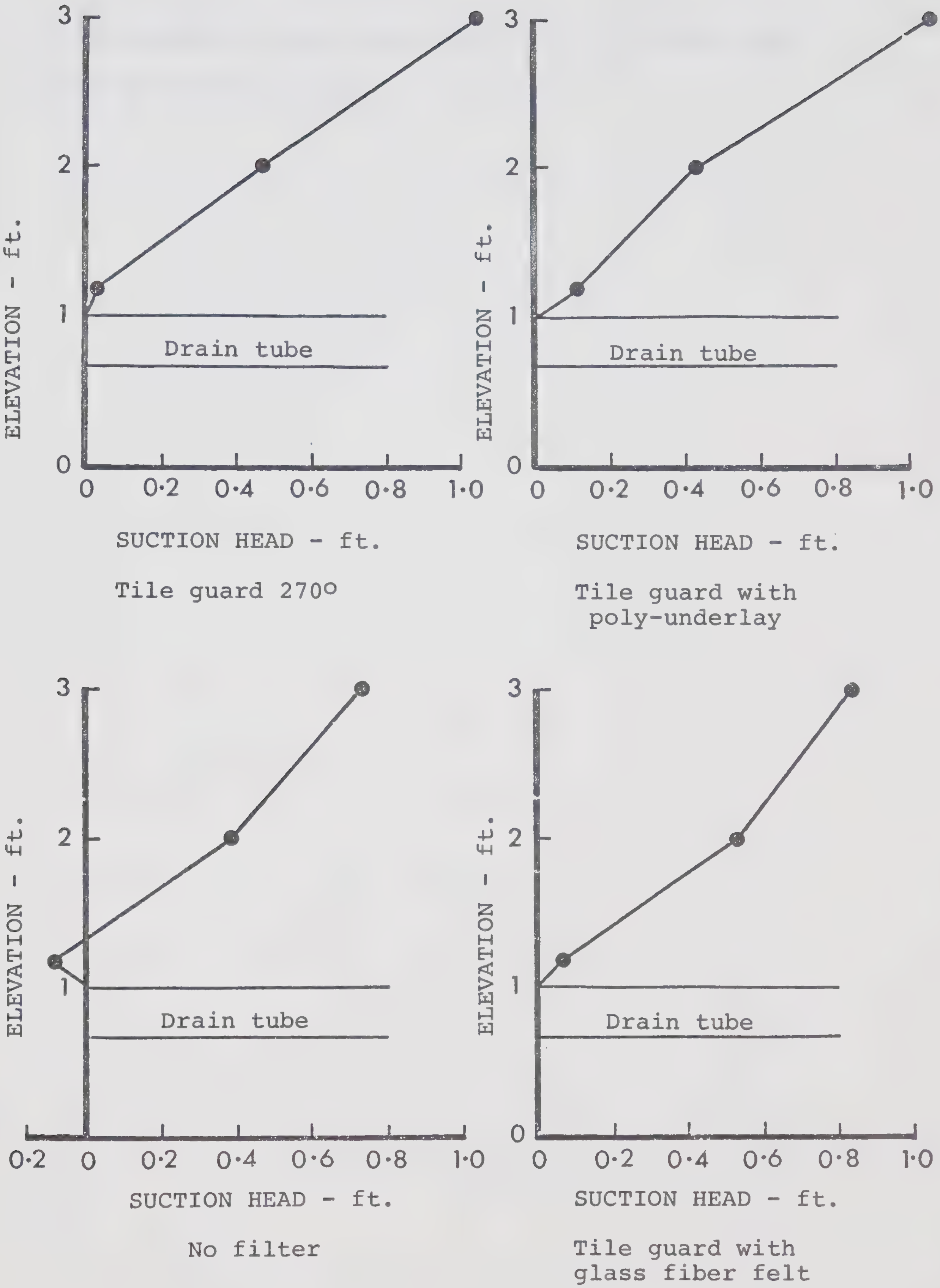

Figure 4.9. (Continued)

will be created in the drain tube and in the base soil outside of the drain tube.

Chapter 5

SUMMARY AND CONCLUSIONS

The problem of drain tile failure does not seem to be very serious in medium-textured loam soils, as it is in light-textured sandy soils. Nevertheless, it can be a critical problem and needs thorough investigation for development of a satisfactory solution.

During the last 50 years, several agencies and workers have developed criteria for design of gravel filters. However, only during the last decade some effort has been made to evaluate other filter materials like glass fiber. Not much is known of the extent of the problem in Canada and only during the last few years has there been some work done in Ontario to evaluate materials and methods of protecting underground drains against silting.

In this study, a medium-textured soil representing this area was selected as a base soil and seven filter materials or combinations of materials were compared in a laboratory model to determine their relative effect on flow of sediments and water into a plastic drain tube. Drain tube having two types of perforations was used in the study. The seven filter materials or combinations of materials were:

1. Gravel filter.
2. Glass fiber mat 270o.

3. Glass fiber mat with glass fiber felt.
4. Glass fiber mat with poly-underlay.
5. Tile guard 270°.
6. Tile guard with glass fiber felt.
7. Tile guard with poly-underlay.

The drain tank models, built of plywood, were each 48 inches deep, 18 inches wide, and 12 inches long. Corrugated plastic tubing of four inches inside diameter was used.

Each test run was of five hours duration, consisting of an initial two and one half hours of ponded water flow and a final two and one half hours of partially saturated flow through the soil profile. The following measurements were made:

1) Rate of water flow through the drain for both flow conditions.
2) Soil discharged during the entire cycle.
3) Pressure head around the drain for both flow conditions.
4) Suction head in the soil profile during the partially saturated flow.

A statistical analysis was performed to determine significant differences between filter materials and perforation types on the amounts of soil and water discharged.

The results and conclusions are as follows:

1 - With no filter material, the amount of

sediments collected in the drain was very high as compared with other treatments.

2 - The amount of soil and water discharged into the drain for different filter materials was significantly different. However, perforations type did not affect significantly either the soil movement or the water discharged.

3 - The glass fiber mat with glass fiber felt, tile guard with glass fiber felt, and the glass fiber mat with poly-underlay, ranked in that order, provided the best protection against sediment movement. There was no significant difference between any two of these combinations. Tile guard with poly-underlay ranked fourth in providing protection against soil movement. While this was not significantly different from glass fiber mat with poly-underlay, it was significantly different from glass fiber mat with glass fiber felt and tile guard with glass fiber felt. Glass fiber mat 270° and tile guard 270° provided comparatively poor protection and ranked fifth and sixth respectively. However, these treatments provided significantly better protection than the gravel filter.

4 - Significant changes in the composition of the original soil and the soil moved into the drain occurred under all treatments. Some subsoil, as well as the top soil, was carried into the drain. The pore size distribution for both glass fiber mat and tile guard is

such that they can make a good protection filter against sedimentation.

5 - The amount of water discharged was significantly higher with gravel filter and was significantly lower under the no-filter treatment as compared with other treatments. The remaining six treatments ranked as follows:

(1) Tile guard with glass fiber felt.

(2) Glass fiber mat with glass fiber felt.

(3) Glass fiber mat 270°.

(4) Tile guard 270°.

(5) Glass fiber mat with poly-underlay.

(6) Tile guard with poly-underlay.

6 - Glass fiber mat with poly-underlay and tile guard with poly-underlay provided significantly better protection against sediment movement than glass fiber mat 270° and tile guard 270°, but showed significantly lower water flow as compared to the same.

7 - For both soil and water discharged, glass fiber mat and tile guard did not differ significantly from each other under similar conditions. However, both materials gave significantly different results between various placement conditions or combinations. Thus, both materials have the same characteristics as a filter. A major problem with any of these two materials could

be the tensile strength. The material having a high tensile strength and greater resistance to tear will be a better choice, especially when used with the plow-in method.

Chapter 6

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